MQP-SL1-MBTA

TRANSIT-ORIENTED, MIXED-USE REDEVELOPMENT WITH INFRASTRUCTURE IMPROVEMENTS IN SOMERVILLE, MA

A Major Qualifying Project Report:

Submitted to the Faculty of

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

By

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Date: April 26, 2012

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Abstract

With the MBTA Green Line Extension to Somerville, an economic opportunity exists to transform the light industrial Inner Belt Core neighborhood through transit-oriented, mixed-use redevelopment. This project provides a vision for such redevelopment based on *highest and best use* and *state-of-the-art design*. Urban planning guidelines were used to develop design, including infrastructure requirements to improve multimodal access and street-level enhancements. The final vision is a revitalized, groundbreaking commercial and residential Inner Belt Core.

Acknowledgements

This project would not have been possible without the support of a number of individuals and institutions.

We would like to express our gratitude to the Somerville Chamber of Commerce, for the opportunity to contribute to Inner Belt/ Brickbottom planning efforts. In particular, we thank Mr. Stephen Mackey, CEO of the Chamber, for graciously taking the time to show us the area and share his knowledge of Somerville and local planning initiatives.

The City of Somerville was likewise supportive of the project. Thank you especially to Hayes Morrison, Director of Transportation and Infrastructure, for meeting with the project team and updating us with key information.

Thank you to our advisors, Professors Leonard Albano and Suzanne LePage of WPI's Civil and Environmental Engineering Department, whose excellent direction and insightful critique were instrumental in the development of this project.

Finally, the project team is thankful for WPI's project-based curriculum, which we believe is the hallmark of a WPI education—*lehr und kunst*—and a transformative educational experience.

Executive Summary

Mixed-use redevelopment is changing the way Americans live in the twenty first century. This mode of redevelopment is characterized by walkable, interspersed commercial and residential uses that create a unique environment. A potential area for such redevelopment is located in the Inner Belt Core (IBC) neighborhood in Somerville, Massachusetts.

As a part of environmental offsets for Boston's Big Dig project, the Massachusetts Bay Transportation Authority's (MBTA) is extending the existing Green Line light-rail service through the IBC. The proposed extension will put a station within walking distance of the IBC. Additionally, the larger Massachusetts Department of Transportation (MassDOT) is planning to extend a bike and pedestrian path called "the Community Path" through the IBC along with the extension of the Green Line. With these projects going on, multiple community organizations, government agencies, and private consultants have taken an interest in redevelopment of the IBC. The Somerville Mayor's Office of Strategic Planning and Community Development (OSPCD) established the City of Somerville's goals for redevelopment in response to this interest. The Inner Belt/Brickbottom Plan, developed by Goody Clancy et al., provides key planning in the neighborhood to achieve the goals of the City of Somerville and other community members.

There are some major challenges to redevelopment in this area. One crucial subject of concern is limited connectivity. Currently Inner Belt Road, to the north, serves as the only access point into the IBC and this road is somewhat restricted by a commuter rail underpass, known locally as the Tubes. Coupling this issue is the challenge of pedestrian and bicyclist connectivity to the future Green Line Station and area neighborhoods. The goal of this project is to design an integrated urban layout in Somerville's Inner Belt Core. Specifically, the goal is to provide a vision for a transit-oriented, walkable, mixed-use development, and create an alternative design for the Tubes.

After initial research and development of a vision for redevelopment the project team created five objectives in support of this goal. These objectives are:

1) Redevelopment: Design a vision for transit-oriented, mixed-use development
2) Redevelopment: Plan the transition from light industrial to mixed-use development
3) Redevelopment: Develop a suite of local infrastructure enhancements to promote connectivity
4) Access through the Tubes: Develop a commuter rail underpass design
5) Access through the Tubes: Propose project management techniques for underpass construction

To achieve these objectives, the project team first conducted a literature review investigating *state-of-the-art design* principles in support of *highest and best use* of the future area. The methodology then involved analyzing two local approaches, developing a framework and layout for urban redevelopment, and investigating the requirements for the underpass according to The American Railway Engineering and Maintenance-of-Way Association (AREMA).

Seven key principles for redevelopment, listed below, were identified:

1) Economic Development
2) Mixed-Use Development
3) Connectivity, Walkability, and Modal Variety
4) Identity and Sense of Place

5) Diversity and Mixed Incomes
6) Environmental Sustainability
7) Livable Community

After these general principles were established, the project team developed a vision statement centered around them. The final vision is a revitalized, groundbreaking commercial and residential Inner Belt Core.

Next, vision outcomes detailing how to fulfill the vision were set. Vision outcomes cover such topics as the minimum residential component, intersection frequency, bicycle accommodation, affordable housing, tree-lined streets, green building design, and public spaces. Corresponding design guidelines offered specifics for the vision outcomes. Analyses of a future IBC infrastructure layout developed by Goody Clancy et al. and Assembly Square Mixed Use District, two local approaches to urban planning in Inner Belt/Brickbottom, aided in refining the design vision for the Inner Belt Core. With this feedback, a baseline infrastructure layout map for the area was created that implements applicable vision outcomes. This map features the Somerville Community Path as a crucial component of improved accessibility and source of economic opportunity for the area. The design also includes an improved street network centered around a vibrant Inner Belt Road and a redesigned Commuter Rail Underpass.

The proposed Commuter Rail Underpass design addresses the problems created by the Tubes by integrating multi-modal use. The design provides access underneath the bridge for two lanes of vehicle traffic, two bike lanes, and two sidewalks, while supporting the Commuter Rail above. Specifically, the design consists of a precast reinforced concrete deck, structural steel stringers, lateral bracing, and two semi-gravity reinforced concrete retaining walls. Through a cost estimate, the construction of the underpass is projected to cost $971,500 for the year of 2012. Assuming normal eight hour work days, the project is estimated to take seventy-one days to complete. To facilitate managing the project, the team provides proposed areas for site storage, a detour for vehicle traffic, and a way to re-route the Commuter Rail train line. Specifically, the vehicle detour will go through a fire lane located near the site and the train will change tracks and travel through a maintenance facility located near the site.

After the project team completed design of their vision for the Inner Belt Core, they next explored the transition from the current development to mixed-use, transit-oriented, state-of-the-art design. Land use controls needed to shape redevelopment in order to achieve vision outcomes were identified. The transition plan also discusses market timing and phasing and property ownership issues that ensure the feasibility of the project.

Authorship

All the authors—Derek Andersen, Katrina Crocker, and Evan Sullivan— contributed to development of the project and they reviewed all sections of the report, and many chapters contain significant writing from multiple team members. Notwithstanding this collaboration, a single team member was ultimately responsible for the final edited state of each major section of the report. Below is an account of the report's authorship.

Derek Andersen was responsible for the chapters on Commuter Rail Underpass Methodology and Commuter Rail Underpass Design, the capstone design statement, and the Executive Summary. He was also responsible for the consolidation and formatting of the final report as a whole, including title pages, and tables of contents and figures.

Katrina Crocker was responsible for the chapters of the Introduction, Conclusion, Urban Planning Methodology, A Framework for Innovation, Somerville Context, Redevelopment Transition Plan, as well as references and acknowledgements.

Evan Sullivan was responsible for the chapters of the Background, A Framework for Innovation, Somerville Context, as well as Design and Implementation methodology, maps, and illustrations.

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Capstone Design

This project meets the requirements of the capstone design experience for a WPI Major Qualifying Project, as defined by the Accreditation Board for Engineering and Technology (ABET). ABET defines criteria that assures each engineering student is capable of attaining a certain standardized level of engineering proficiency, regardless of the school or program they attend. ABET General Criterion 3(c) states that "[each student will demonstrate] an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability." The feasibility of this project is dependent upon the application of these constraints to three major design components: the design of future transit-oriented, mixed-use redevelopment in the Inner Belt Core, the design of the Community Path as well as the street layout through the area, and the design of a new Commuter Rail Underpass.

Economic

When planning redevelopment, the future market for various property uses is of primary importance for feasibility, therefore market projections and analyses were considered. Similarly, economic factors for residents and local businesses were included while planning to maximize feasibility as well as economic gains. Consideration of economic constraints and opportunities is fundamentally rooted in design as a key goal of redevelopment to increase Somerville's economic base.

Economic factors are critical in the design of the Community Path through the Inner Belt Core neighborhood. The Path is faced with significant engineering challenges due to the required clearance of multiple MBTA railway sections and construction expenses may limit feasibility.

The design of the Commuter Rail Underpass provides a cost estimate for the construction of this project and predicts the cost of construction now, five, ten, and twenty years from now. This cost incorporates the material, labor, overhead, and profit costs of construction, and incorporates miscellaneous costs such as insurance, office expenses, and geotechnical investigations. The design attempts to minimize the cost of the project, while balancing the time and scope of the project. Finally the design insures that enough money is spent so as to meet the appropriate design guidelines and codes.

Environmental and Sustainability

The project team's designs were developed in the context of placing high priority upon environmental and sustainability excellence. LEED Neighborhood Design guidelines were at the heart of the development of the project team's design guidelines. Existing planning approaches in the area of study were assessed based on these design guidelines, and critical connectivity infrastructure enhancements recommended by the team were based on this design. This project inherently addresses issues pertinent to enhancing sustainable transportation and living practices in the Inner Belt Core.

Transit-oriented redevelopment in the Inner Belt Core (IBC) has historic background in environmental considerations, as the anticipated Green Line Extension project was proposed as a solution to mitigate the region's air quality issues. Extending light-rail service from downtown Boston through Somerville and north to Medford is intended to reduce the amount of regional automobile emissions. The Somerville Community Path for pedestrians and bicycles is another important environmental aspect of the Green Line Extension.

The IBC specifically capitalizes on the transit-oriented nature of the redevelopment in order to control vehicle miles travelled (VMT) in the region, ensuring access to the proposed nearby Washington St. Station of the Green Line Extension (GLX) as well as the proposed Community Path extension. Access to the GLX station enables transit travel throughout the Boston area via the subway and bus system. The Community Path extension, a critical design consideration for this project, enhances pedestrian and bicycle travel to and from the Inner Belt/Brickbottom (IBBB) area, further reducing need for automobiles and potentially reducing vehicle emissions. In addition to the Community Path, the Commuter Rail Underpass provides a safe pedestrian and bicycle entrance into the area that was not offered by the Tubes.

The redevelopment design maximizes walkability in IBC. Altogether, non-car dependent travel reduces harmful combustion pollutants that contribute to poor air quality and global warming. Focusing redevelopment in this way coordinates with the key IBBB development plan that the City of Somerville has developed with consultant Goody Clancy, which promotes walkable transportation options and reduced need for automobiles for regional transportation. Providing for environmentally-friendly transportation options is also meets the requirements outlined in the City of Somerville's Comprehensive Plan.

Political

As the project team designed a redevelopment plan in the IBC, we considered potential political constraints to ensure the project is ultimately feasible. The project group worked closely with the Chamber of Commerce and coordinated with Somerville City Hall to ensure designs are in line with the political process and plans for the area. The final design proposal was presented to stakeholders in City Hall and the Somerville's Chamber of Commerce.

Social

In addition to the Chamber of Commerce and Somerville City Hall, multiple community groups and local citizens have a vested interest in redevelopment in the Inner Belt Core. The Community Path extension, championed by local community groups such as Friends of the Path and the Somerville Transportation Equity Partnership (STEP), is a key issue in the Inner Belt area that was incorporated into the Green Line Extension. The project team considered plans for the Community Path posted online by these groups, as well as reached out to them for further coordination. Additionally, the group attended public meetings concerning redevelopment in IBBB to obtain an understanding of the public's opinions and feelings regarding the Green Line Extension and corresponding plans for redevelopment.

Ethical

The Major Qualifying Project follows the code of ethics defined by the American Society of Civil Engineers (ASCE). The code of ethics states, "Engineers will uphold and advance the integrity, honor and dignity of the engineering profession…" (American Society of Civil Engineers, 2011). This project provides results and designs to the proper parties involved in a professional manner. To the best of the project group's knowledge, these results and designs are truthful, provide proper recognition to cited sources, and meet all required guidelines and codes defined by ASCE.

Health and Safety

The neighborhood's accommodations for rail, pedestrian, bicycle, and vehicular access required designs that provide appropriate considerations for safety. Designs for the integrated Community

Path, street layout, and Commuter Rail Underpass meet all regulations as defined by the appropriate local, state and federal laws. Designs also address safety constraints through compliance with the Americans with Disabilities Act (ADA). Integrating the Community Path and opening up access through the Commuter Rail Underpass promotes healthy forms of transportation and reduces automobile emissions, supporting larger transportation goals outlined in guidelines such as GreenDOT, the Massachusetts Department of Transportation's (MassDOT) Sustainability and Livability Policy Framework.

Constructability

The constructability of the integrated urban layout and the Commuter Rail Underpass was dependent upon the defined constraints, listed above. The designs provide solutions which considered the feasibility of implementing these projects. They are achievable designs that incorporated the cost and time restraints present, as well as meeting the needs of all involved and affected parties to the best of the group's ability.

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1.0 Introduction

This report begins by establishing the project goal, objectives, and plan; refer to the corresponding sections, below.

1.1 Goal

The goal of this project was to design an integrated urban layout in Somerville's Inner Belt Core (IBC). Specifically, the project team designed a vision for a transit-oriented, walkable, mixed-use development that fulfills the Inner Belt/Brickbottom Plan's vision of a regional focal point of economic activity with a quality sense of place (Goody Clancy et al., 2011a). This vision included a proposed transition to the future. This design crucially addressed connectivity to the MBTA's proposed Washington Street Station and the surrounding area. This connectivity involves extending Somerville's Community Path through the IBC, improving access issues currently posed by the commuter rail culvert ("the Tubes") and promoting increased pedestrian and cyclist traffic through the area. The design was grounded in the principles of social, economic, and environmental sustainability.

1.2 Objectives

The following five objectives were identified for achieving the goal:

1) Redevelopment: Design a vision for transit-oriented, mixed-use development

2) Redevelopment: Plan the transition from the current light industrial to mixed-use development

3) Redevelopment: Develop a suite of local infrastructure enhancements to promote connectivity

4) Access through the Tubes: Develop a commuter rail underpass design

5) Access through the Tubes: Propose project management techniques for underpass construction

1.3 Project Plan

In order to accomplish the goal and five supporting objectives, the project team identified a number of different components to fulfill. The following project plan flow chart, shown in Figure 1, details these components and their location in the development of the project.

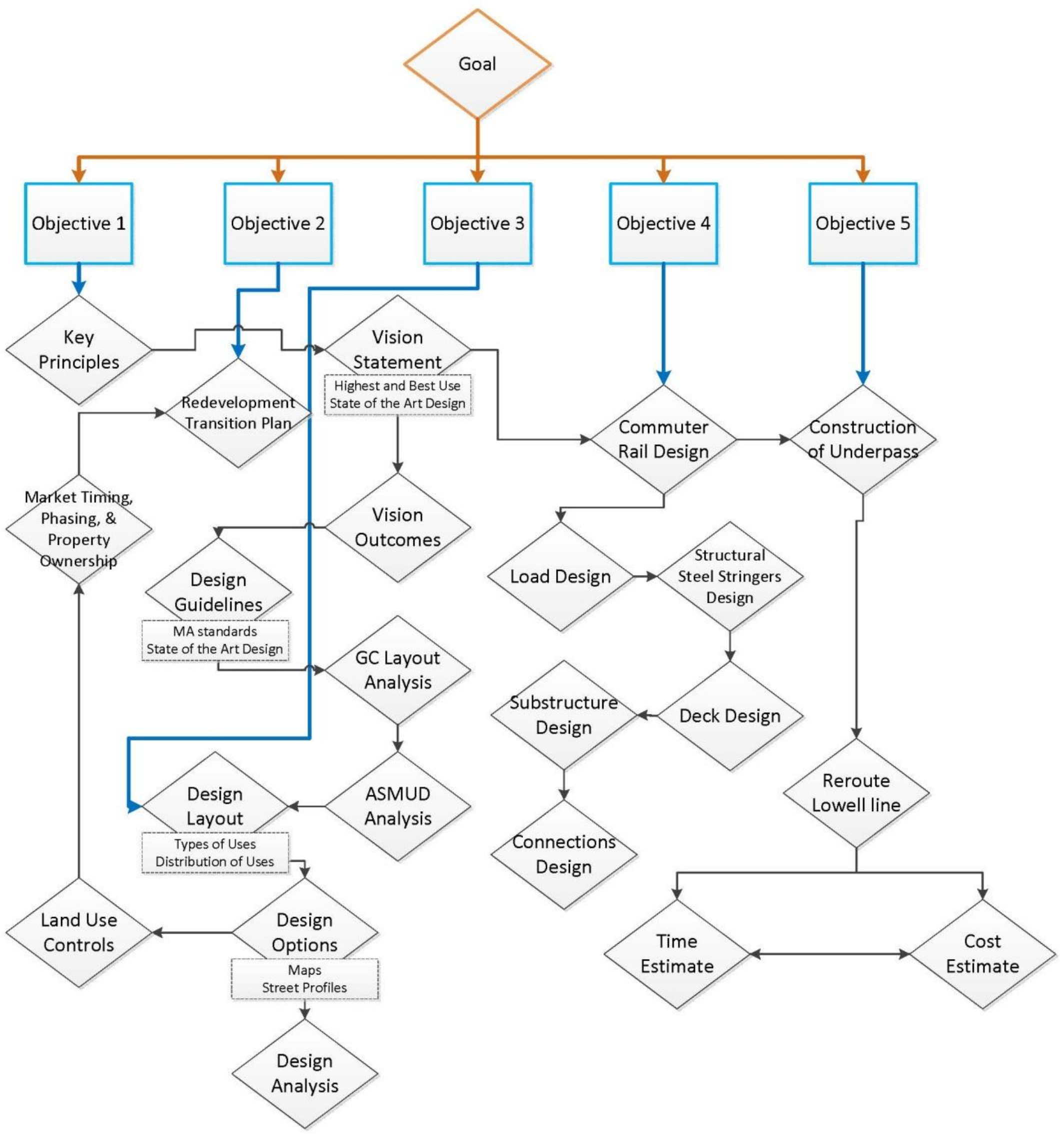

Figure 1 Project Plan and Components

Objective 1–Redevelopment: Design a vision for transit-oriented, mixed-use development—was identified as a critical step for defining the project. The project team prioritized completion of this objective first. The following elements, as shown in the flow chart, were identified as sequential key steps for this objective:

- key principles,
- a vision statement founded on the key principles,
- vision outcomes that provide the basis for implementation of the vision,
- specific design guidelines based on *highest and best use* and *state-of-the-art design*,
- an analysis of two key local planning approaches, the Goody Clancy layout and Assembly Square Mixed Use District,
- a design layout and design options informed by the two analyses and the group's guidelines,
- design analysis and a final design.

The various elements associated with Objective 1 are sequentially discussed over four chapters: Chapter 5: A Framework for Urban Innovation, Chapter 6: Somerville Context: Analysis of Local Approaches, Chapter 7: Design and Implementation of Best Practices, and Chapter 9: Redevelopment Transition Plan

Objective 2—Redevelopment: Plan the transition from the current light industrial to mixed-use development—was prioritized second to Objective 1. This objective consists of recommendations regarding land use controls, market timing and phasing, and property ownership. Together, these compose the final deliverable, a redevelopment transition plan. It was investigated in conjunction with research for Objective 1. Though largely completed independently of Objective 1, it did consider basic features of the design options. Conversely, the design layout and design options developed for Objective 1 also incorporated the transition constraints of land use controls and market timing, phasing, and property ownership. Objective 2 is discussed in Chapter 9: Redevelopment Transition Plan.

Objective 3—Redevelopment: Develop a suite of local infrastructure enhancements to promote connectivity—is defined by the Community Path and street grid, which are defining features in the design layout step. Objective 3 is also represented by the transportation-focused key principle concerning connectivity, walkability, and modal variety. Although this objective plays into Objective 1 relating to the vision, it remains an independent objective of design since it is the foundation for successful design. Increasing traffic access circulation within the area of study was considered a crucial aspect of achieving the economic development goals of the vision. Additionally, traffic needs were considered when setting dimensions for Underpass Design in Objective 4, as the underpass is a main point of vehicular, pedestrian, and bicycle access to the area of study.

Objective 4—Access through the Tubes: Develop a commuter rail underpass design—consisted of the following elements:

- design loads that determine controlling design conditions,
- structural steel stringers design,
- deck design,
- substructure design, and
- bridge connection design

This objective was completed in conjunction with Objective 1, since the engineering calculations were largely independent of the execution of the other objectives. However, the traffic access considerations determined by Objectives 1 and 3 influenced the dimensions of the substructure.

Objective 5—Access through the Tubes: Propose project management techniques for underpass construction—consisted of the following elements:

- rerouting the Lowell Line, vehicles, and pedestrians,
- time estimate, and
- cost estimate

This objective was simultaneously completed with objective 4. Since Objective 4 and Objective 5 deal with the same infrastructure component they are discussed in Chapter 8: Commuter Rail Underpass.

2.0 Background

Chapter 2 provides an overview of topics that together provide a foundation for understanding the project. It describes the area of study, the area's transportation history, stakeholders in redevelopment, themes of redevelopment, and local transportation infrastructure improvements. Approaching this project within appropriate historical context is essential to comprehending the methods and results of this report.

2.1 Area of Study

The Inner Belt/Brickbottom (IBBB) neighborhood is a light industrial area in southern Somerville. Although the Inner Belt and the Brickbottom areas are two separate neighborhoods, they are often coupled because of their adjacent proximity and shared history (OSPCD, 2011). This project is specifically focused on the Inner Belt Core (IBC); a sub-region of Inner Belt defined in Figure 2, and may occasionally refer back to distinct features of the entire Inner Belt or Brickbottom area.

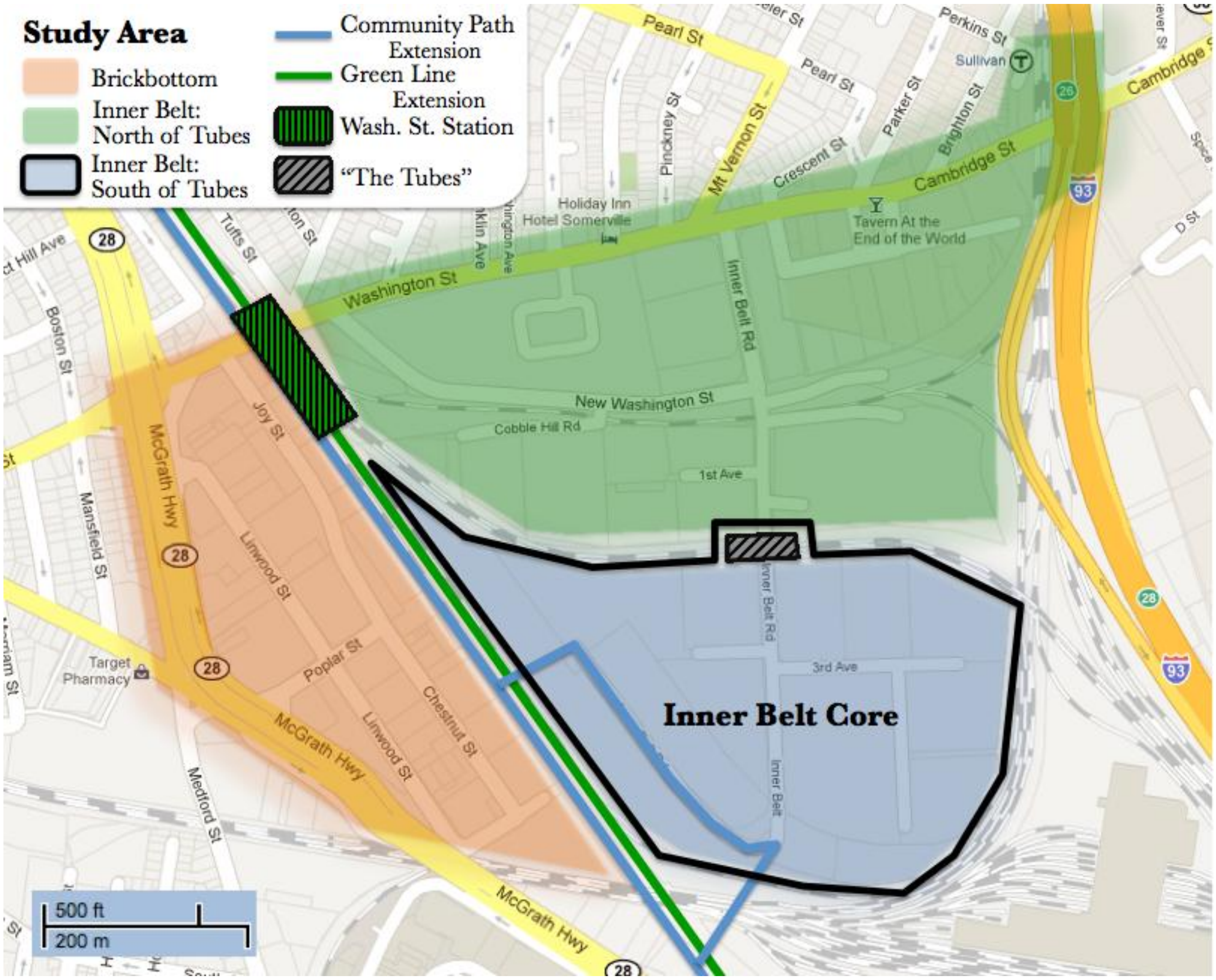

Figure 2 Study Area Map (Google Maps, 2011)

Figure 2 depicts the IBC, which is roughly defined by existing rail lines to the east, the future Green Line Extension to the west, existing rail yards to the south, and a roadway culvert colloquially known as "the Tubes" to the north (City of Somerville, 2011).The IBC contains many low-rise office parks and telecommunications hubs, as well as some manufacturing facilities. One of the Massachusetts Bay Transportation Authority's (MBTA) commuter rail maintenance facilities resides in the IBC. According to the Massachusetts Department of Transportation (MassDOT), plans call for an expansion of the MBTA's maintenance facility property in order to provide operational space for the future Green Line trains that will serve the area.

2.2 Redevelopment In the IBC: Why now?

In 1990, an extension of the MBTA's Green Line light-rail service was planned as a part of a legal obligation to offset the calculated environmental impacts of Boston's Big Dig project. In 2011, project delays were announced as a result of pending applications for Federal funding and ongoing environmental impact assessments. Currently, MassDOT officials are investigating the potential to phase construction of the Green Line Extension (GLX) in order to expedite its construction (Byrne, 2011). An extension of the MBTA's Green Line through Somerville is now scheduled to begin construction between 2018 and 2020.

The GLX project is rooted in social, environmental, and economic equity concerns. Many Somerville residents lack viable pedestrian access to Boston's extensive commuter rail and subway system. Regardless of this, the City tolerates many of the burdens that are associated with urban transportation infrastructure. Somerville is home to the MBTA's Commuter Rail maintenance facility, a sizable property and operation that cannot be taxed at the local level. Eight passenger rail lines extend through Somerville; however Davis Station is the only MBTA subway station located within Somerville's city limits (Somerville Transportation Equity Partnership, 2011).

Somerville not only lacks substantial passenger rail access while hosting an MBTA maintenance facility, but the City also retains many major highways. Interstate-93 and Massachusetts Route-28 (McGrath Highway) are essential roadways for many regional and local automobile users; however, the automobiles that often congest these roadways degrade Somerville's air quality

(Somerville Transportation Equity Partnership, 2011). Additionally, the rate of traffic and elevated design of these roads disrupt Somerville's urban layout and are barriers to neighborhood connectivity and economic development. Many of Somerville's residents, community groups, businesses, and politicians identify the GLX as a strategic transportation resource that provides ample opportunity for economic development.

Another future transportation resource expected to impact Somerville is the improvement of an existing bike and pedestrian path called "the Community Path." Constructed on a former railroad right-of-way, the Community Path was built to reduce automobile trips, promote alternative commuting practices, and encourage recreation (Friends of the Path, 2011). This pedestrian and bicyclist right-of-way is available to users in northwestern Somerville near Davis Square and extends west into neighboring Medford. The eastern terminus currently lies at Cedar St. in Somerville. To complement the GLX's local transportation improvements, MassDOT is planning an extension of the Community Path from Cedar St. to the Charles River paths. Both the GLX and the Community Path will run parallel to each other through southern Somerville. Depictions of the GLX, the Community Path extension, and their related proximities to the IBC are available in Figure 2.

Both the Green Line Extension and the Community Path extension are vital undertakings relevant to IBC's redevelopment. The GLX's proposed Washington St. Station is within walking radius to most locations in the IBC, making the area a viable option for transit-oriented development. To complement the district's redevelopment potential, the Community Path extension will enhance the IBC's pedestrian and bicycle connectivity.

2.3 Stakeholders

The future of IBBB will depend on a range of voices, decisions, and actions executed on behalf of various organizations. These organizations are interconnected and play significant roles pertaining to this project. Figure 3 illustrates the categories and roles these organizations hold.

Figure 3 Key Organizations Impacting IBBB Development

Although these organizations have different types of support and privileges, they are proceeding communicably to realize the IBBB’s full potential. Goody Clancy conducts planning research and develops design ideas for Somerville’s Office of Strategic Planning and Community

Development. It is responsible for gathering information pertinent to Somerville's future use of the IBBB area and relaying this information to the City of Somerville (Goody Clancy et al., 2011a). This is not the only government bureau and private firm partnership relevant to the IBBB area. The HDR and Gilbane engineering firms are responsible for GLX design and construction work. They are incorporating an extension of the Community Path along the Green Line Extension's route in Somerville (Commonwealth of Massachusetts et al. 2011a).

Community organizations represent the collective interests of a group of stakeholders. The Somerville Chamber of Commerce, who provided the opportunity for this MQP, is the voice of 380 member companies and organizations and promotes Somerville's economic opportunities (Somerville Chamber of Commerce 2008). Some members of the Chamber of Commerce own property in or around the IBBB and maintain close social and financial relationships with the area. In parallel, The Somerville Transportation Equity Partnership (STEP) is the foremost voice of community members calling for enhanced transit resources in Somerville (Somerville Transportation Equity Partnership, 2009). STEP enthusiastically supports the GLX and is an organization that politically empowers interests related to the GLX. Friends of the Path is another community group that is seizing the GLX as a transit opportunity. It is specifically concerned with politically backing the extension of a local bicycle and pedestrian path, known as the Community Path, along the future GLX right-of-way (Commonwealth of Massachusetts et al., 2011b).

2.4 IBC's Future Vision

With municipal, commercial, and residential support from the stakeholders identified in the previous section, land uses in the IBC can evolve to fully seize the opportunities of the new transportation resources provided by the Green Line Extension. Two sources together comprise leading local views for the project area, and locally appropriate redevelopment designed by the project team achieves these goals. First, the Somerville Mayor's Office of Strategic Planning and Community Development (OSPCD), representing municipal support, establishes the City of Somerville's goals for redevelopment in IBBB in their Squares and Neighborhoods page (OSPCD, 2011). Second, the Inner Belt/Brickbottom Plan is a key collaboration of visions for the area led by the City that draws upon varied support from "residents, City staff, businesses, organizations, institutions, and other stakeholders working together" (Goody Clancy et al., 2011a).

The City of Somerville sets the following six goals for redevelopment of IBBB:

- Create mixed-use development;
- Enhance transit access;
- Rework infrastructure;
- Strengthen the public realm by creating open space;
- Connect to a network of accessible districts; and
- Leverage life sciences and institutional convergence with neighboring university facilities (OSPCD, 2011).

The IBBB Plan, representing a range of community views, in turn establishes the following broad vision and opportunities key to the vision for redevelopment in IBBB:

- Creating a new mixed-use Somerville neighborhood of choice.

  …a place that attracts skilled and educated workers, and therefore significant investment

…an amenity and source of economic opportunity for Somerville…and the region (Goody Clancy et al., 2011b).

- Expanding Somerville's job base by leveraging its own high-quality workforce and connections to high-quality regional workforce;
- Expanding Somerville's commercial tax revenues through expanded business activity;
- Leveraging life sciences and institutional convergence with university facilities near the study area;
- Creating recreation opportunities serving all of Somerville (Goody Clancy et al., 2011a).

The IBBB Plan calls for the following means for achieving these goals:

- Mixed-use development including new housing and retail options as well as office and research;
- Enhanced transit access;
- Safe, inviting pedestrian connections within and beyond the study area;
- More convenient vehicular connections;
- Extension of the Somerville Community Path and creation of new public park space;
- Distinguished streets, parks and architecture that lend a strong new identity to this area and all of Somerville (Goody Clancy et al., 2011a).

Together, both of these envision transformation of the current light industrial, low-density layout of Inner Belt/Brickbottom into a transit-oriented, mixed-use development district.

The emerging plan, still in progress, seeks to capture the new potential of Inner Belt/Brickbottom by making it a new regional focal point of economic activity with a quality sense of place. Strategic urban planning is needed to transform the area from a light industrial park into a mixed-use development community. Determining the optimal mixed-use development strategy in order to increase economic potential and create a sense of place is an important consideration for this project, as dense centers of commerce and civil interaction have been associated with numerous environmental, economic, and social advantages (Good Clancy, 2011). Corresponding design considerations include walkability, proximity to storefronts, and landscape architecture. Planning the transition of this area through zoning strategies and market incentives is an important step in achieving such a desired transformation.

Challenges associated with this vision are varied. Perhaps the biggest physical challenges to be tackled by urban planners are poor access and circulation infrastructure. Planning is similarly needed to create walkability. Another challenge specific to the area is enhancing its sense of Somerville character, particularly since the area faces market competition with other sites. Significant phasing and financing implementation difficulties provide economic challenges. Political challenges also exist in developing and sustaining political will, understanding, and support (Goody Clancy et al., 2011b). Plans for redevelopment must address these challenges for success.

2.5 Development Challenges: Limited Connectivity

As discussed in the previous section, limited connectivity is a significant barrier to development opportunities in the Inner Belt Core. The IBC is isolated from surrounding neighborhoods by railroad tracks and highways. Reworking infrastructure is one of six goals named by the Mayor’s Office of Strategic Planning and Community Development (OSPCD, 2011). This section discusses two access improvements that are key to addressing limited connectivity: the Community Path and the Commuter Rail Underpass.

2.5.1 Community Path

The Community Path is a pedestrian and bicycle spur of the Minuteman Bikeway, which extends 11 miles south-eastward from the I-95 corridor of Bedford, MA to Somerville, MA, as can be seen in Figure 4, below. The Community Path begins at Somerville's multi-modal hub of Davis Square, geographically northwest from the center of Somerville. Currently the path terminates at Cedar St., a location roughly geographically central to the rest of Somerville. To maximize path functionality, the MBTA has incorporated Community Path extension plans into Green Line Extension designs (Friends of the Path, 2011). This path extension would connect the path to the Charles River, fully optimizing the Community Path's role as part of a regionally integrated resource for pedestrians and bicyclists from downtown Boston to Bedford and beyond.

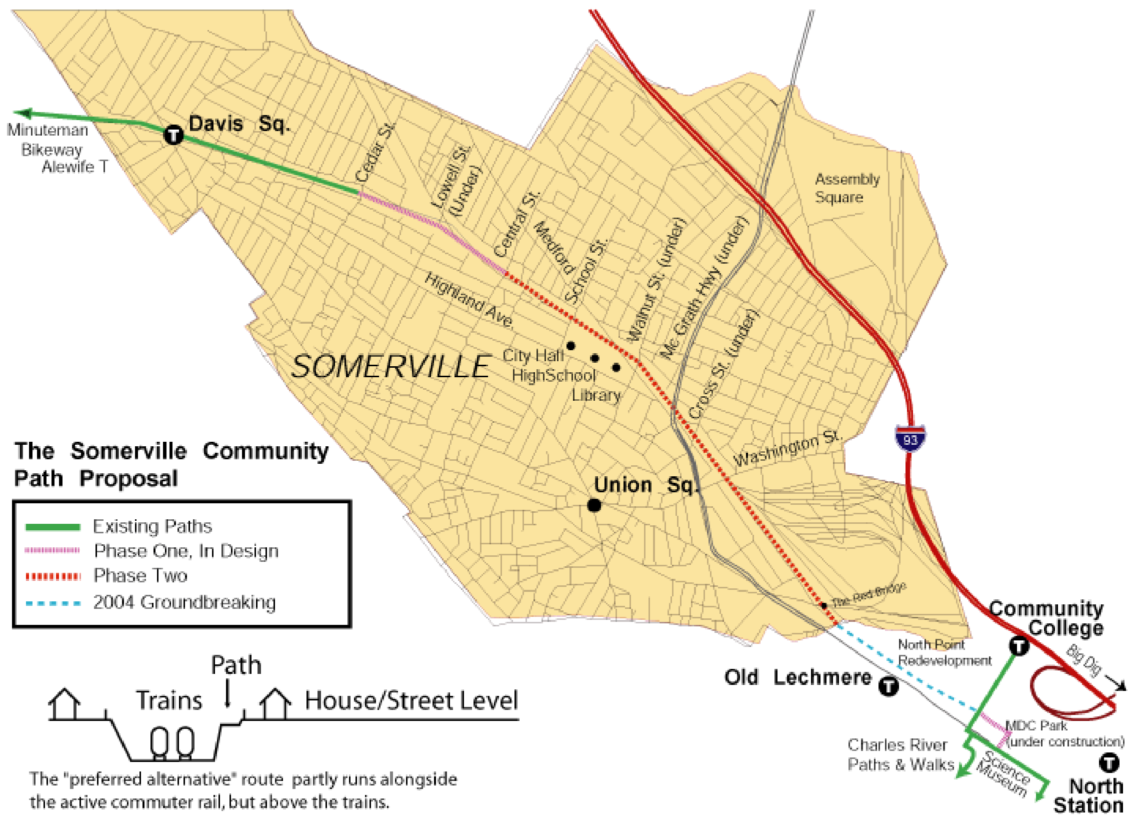

Figure 4 Illustration of existing path, and plans for South Eastward expansion towards the banks of the Charles River and Boston proper (Friends of the Path, 2011)

Although extension of The Community Path along the GLX is imminent, specific designs for linking The Community Path to the IBBB remains a topic for further discussion and planning. If the linkage was made, it would likely increase pedestrian and bicycle traffic between Washington St. Station and the IBBB, reducing travel time and distance for pedestrians.

An extension of the Community Path into the IBBB area would help to fully achieve transit-oriented development in the IBBB area. While the Green Line Extension's proposed Washington St. station is expected to generate pedestrian traffic near the Inner Belt/Brickbottom area, transit riders leaving the station would encounter difficulty accessing the Inner Belt Core. Currently, Inner Belt Road is the only public point of vehicular and pedestrian access to the IBC, which requires pedestrians, bicyclists, and vehicles to travel through the commuter rail underpass on Inner Belt Road. Since Inner Belt Road is not a throughway and terminates as a dead-end, few travelers are compelled to enter the area unless it is their destination. Providing additional access points and improving current accessibility infrastructure are likely keys to increasing the economic viability of development in the Inner Belt.

2.5.2 Limited Access at the Tubes

Inner Belt Road is currently the only access point into and out of the Inner Belt Core (IBC). During the late 1970's a team of engineers constructed a railway underpass for street traffic, known as "the Tubes," over Inner Belt Rd to accommodate the Lowell Commuter Rail Line (Mackey, 2011). The Tubes provide street access into and out of the IBC and connect the Lowell Commuter Rail Line between the West Medford station and North Station. At the time, the engineers designed the tubes to be a temporary structure. However, they remain today, and while they do facilitate traffic into the IBC, the Tubes pose a few problems that are compounded by the fact that they are the only access point for the area.

Figure 5 Street View of the Tubes (Crocker, 2011)

The cramped, oval design of the Tubes, shown in Figure 5, imposes limitations upon traffic. The Tubes create a tight clearance for vehicles, strictly limit sidewalk capacity, and do not offer space for bicycles to travel in their own lane. The clearance restricts certain vehicles from entering the industrial park, and large trucks have even become temporarily lodged in the Tubes. Furthermore, vehicles have struck and damaged the Tubes, as can be seen in Figure 6 below (Mackey, 2011). The narrow sidewalks, approximately two and a half feet wide, restrict pedestrian flow and pose potential danger to pedestrians due to the close proximity of vehicles traveling through the Tubes. Additionally, the dimensions prevent bikes from sharing the road with vehicles. In 2011, a report for the Somerville police indicated a bike crash occurred at the tubes in 2010 (Reported Bike Crashes, 2011). Although the Tubes permit most vehicles, they cannot accommodate simultaneous modal uses.

Figure 6 Structural Damage to the Tubes (Donovan, 2011)

Even with these problems, there are equally as many challenges to redesigning the Commuter Rail Underpass. The group estimates the height from street level to the bottom of the rail is nineteen feet. The minimum clearance for a bridge to not be labeled a low clearance bridge is thirteen and a half feet, so a new design might want to conservatively shoot for fourteen feet (MassDOT, 2012). This clearance limits the overall depth of any new construction to about five feet. Although this may seem sufficient, approximately the first couple of feet will need to accommodate railroad ties and ballast, which is the crushed stone the tracks rest on (AREMA, 2003). The general requirements for a ballasted railway bridge require one foot of ballast below the rail ties, which are already seven to eight inches in depth. This further reduces a bridge design to just over three feet for a deck and supporting members on a structure, and depending on the span of the bridge, this could prove to be challenging.

As displayed in Figure 7 below, the bridge would need to support two train tracks. These tracks are for train lines that run into the City of Boston, so the project needs to address dealing with a train line that serves a major city. Another challenge, which is common in many projects, is the cost. With the restrictions listed above and the issue of closing the train lines at the site, the cost of this project could be large. The City of Somerville has other large scale construction projects going on, so this has not been a high priority according to Director of Transportation and Infrastructure, Hayes Morrison (personal communication, October 13, 2011). Overall there are many challenges to this project, which is one reason why it hasn't been addressed.

Figure 7 - Existing Commuter Rail Lines (Donovan, 2011)

2.6 Summary

The Green Line Extension will bring many changes to Somerville. As a transit resource, the MBTA's extended Green Line light-rail service has the potential to reshape commuting patterns and the character of many existing communities. The Inner Belt and Brickbottom of Somerville will be one of the most heavily influenced areas. With the construction of Washington St.

Station, the IBC’s light-industrial land uses may become less viable and other land uses will compete to acquire the area’s transit orientation. At this juncture, understanding the IBC’s potential future is a necessary task. Chapter 3 and Chapter 4 of this report will outline the Methodology for addressing these problems.

3.0 Urban Planning Methodology

Chapter 3 discusses the methods used by the project team to design the elements identified in the project plan. Each section of the chapter corresponds to subsequent chapters. Section 3.1 discusses the methodology used for Chapter 5: A Framework for Urban Innovation. Section 3.2 contains the methodology for Chapter 6: Somerville Context: Analysis of Local Approaches. Section 3.3 corresponds with the methodology for Chapter 7: Design and Implementation of Best Practices; and Section 3.4 with Chapter 9: Redevelopment Transition Plan. The structural design methodology followed for the development of Chapter 8: Commuter Rail Underpass Design is presented in Chapter 4: Commuter Rail Underpass Methodology.

3.1 A Framework for Urban Innovation

A framework for urban innovation was developed from the following project elements identified in the Introduction:

- key principles,
- a vision statement founded on the key principles,
- vision outcomes that provide the basis for implementation of the vision, and
- specific design guidelines based on *highest and best use* and *state-of-the-art design*.

Seven key principles for redevelopment of the Inner Belt Core were identified as the first step to fulfilling Objective 1, to design a vision for transit-oriented, mixed-use development. Key principles were drawn as common values and identified themes that are repeated in a number of different urban planning works that reflect *highest and best use* and *state-of-the-art design*.

The vision statement was then developed from the key principles through research. The selection of each key principle was explained in terms of *highest and best use* and *state-of-the-art design*, affirming that each *key principle* reflects the City of Somerville's goals for redevelopment and represents the latest thinking in urban planning, respectively.

Highest and best use refers to land use ideas most beneficial for a specific area. The project team identified the City of Somerville's Inner Belt/Brickbottom (IBBB) Plan as a central source for determining *highest and best use* since it reflects the official ideas of the local government (Goody Clancy et al., 2011a). Likewise, supporting documents on the City of Somerville website were extensively used to represent *highest and best use*. Examples of such documents include *Comprehensive Plan 2010-2030* (City of Somerville, 2010) and "Implementing Transit-Oriented Development: Strategies and Tools" (Zimbabwe, 2010). The IBBB Plan and other City of Somerville documents were thus an important reference for creating *key principles*.

State-of-the-art design refers to the latest scientific thinking from reputable institutions regarding different aspects of design. The project team identified *LEED 2009 for Neighborhood Development Rating System* (LEED-ND) as a crucial source of *state-of-the-art* urban planning. Developed by the U.S. Green Building Council, Congress for New Urbanism, and Natural Resources Defense Council, LEED (Leadership in Energy and Environmental Design) rating systems are an "internationally recognized as a standard of excellence" (USGBC, 2011b). LEED-ND in particular is a cutting-edge development since it is the first national system for neighborhood design (USGBC, 2011a). This reference became a cornerstone of the project team's key principles.

A select number of other seminal urban planning works were also determined to be strong sources representing *state-of-the-art* design. Jane Jacobs' *The Death and Life of Great American Cities*, widely renowned and cited, is one such source regarding progressive urban planning considered part of the New Urbanism movement. *Reclaiming the City: Mixed Use Development* by Andy Coupland builds off of Jacobs' work, in addition to a number of others. Durham-Jones and Williamson's *Retrofitting Suburbia: Urban Design Solutions for Redesigning Suburbs* was a more modern influential resource, named by the American Society of Landscape Architects (ASLA) as one of three key resources on sustainable urban development professional practice (ASLA, 2008). The ASLA's *Livable Communities* policy was also considered a highly knowledgeable source from which to draw key principles for forming the vision. *Site Planning and Design Handbook* by registered landscape architect and environmental manager Thomas H. Russ, was considered a useful planning source incorporating sustainability.

The project team established a vision statement centered around the key principles. They next developed vision outcomes, different aspects or measures of development that accomplish each of the seven key principles as discussed in the vision statement. In other words, the vision outcomes are specific, qualitative means of implementing the key principles. These aspects are drawn from *state-of-the-art* urban planning. *LEED 2009 for Neighborhood Development Rating System* (LEED-ND) heavily shaped the development and organization of the vision outcomes, even as discussion of each vision outcome was drawn from a variety of sources.

In conjunction with the development of vision outcomes, the Design Guidelines were researched. The design guidelines offer more quantitative metrics for redevelopment that meet the vision outcomes. They are organized by larger category of key principle and sub-category of vision outcome. The design guidelines, like the vision outcome, were often drawn from *LEED*

Neighborhood Development Rating System. They were also supported by other works representing *state-of-the-art design* as available, and incorporated Massachusetts standards and regulations.

3.2 Somerville Context: Analysis of Local Approaches

After developing vision outcomes and design guidelines, the project team examined existing related local development to see how well their planning strategies matched this local development. First, two local development projects were identified as targets for this analysis: a Goody Clancy layout map development for the Inner Belt/Brickbottom Plan (IBBB Plan) and the City of Somerville's land use controls for a local mixed-use development district, Assembly Square. Next, the project team examined the two approaches to local development in terms of fulfillment of the vision outcomes and agreement with the design guidelines. The group concluded analysis of each local approach with a discussion of its key elements and their applicability in the project team's design. These analyses emphasize applicability to the project team's own designs rather than attempt to exhaustively assess the local approaches.

Goody Clancy has developed an Inner Belt/Brickbottom Plan for the City of Somerville, including a basic layout of redevelopment that aims to fulfill the City's values. The basic elements of Goody Clancy's street layout were discussed by the project team according to importance and feasibility. The project team will apply some of their street grid and connectivity ideas, although not all of them will be incorporated in our design.

Assembly Square Mixed-Use District is a mixed-use development site in the square by the same name neighboring IBC. Somerville has developed a comprehensive document compiling mixed-use development guidelines for the district which aided in the project team's design of a redevelopment transition plan. Information from this new zoning precedent was applied judiciously to the project, as the nature of the Inner Belt area does differ from that of Assembly Square in some respects.

3.3 Design and Implementation of Best Practices

A connectivity layout of key infrastructure improvements was first created as the basis for redevelopment in Inner Belt Core. Types and distribution of uses within the neighborhood were discussed in conjunction with this layout. A street profile for the main throughway, Inner Belt Road, was also designed. The maps were creating utilizing Microsoft PowerPoint presentation software based off of satellite imagery of the area and highlighted key features of development. The street profiles were developed in Google SketchUp 3D modeling software according to previously identified design guidelines concerning dimensions aesthetics. Complimetary visual effects such as scale models of vehicles, bicycles, trees, pedestrians, benches, street lights, and train tracks were imported from the Google 3D Warehouse. Both the connectivity layout and street profile were designed according to their ability to fulfill the vision outcomes and meet the design guidelines.

3.4 Redevelopment Transition Plan

In order to design a redevelopment transition plan, the project team researched land use controls, market timing and phasing, and property ownership. Key references include *Understanding the Law of Zoning and Land Use Controls* by Barlow Burke, the *Commercial and Mixed Use Development Code Handbook* of the Oregon Transportation and Growth Management (TGM) Program, and *Land-Use Planning for Sustainable Development* by Jane Silberstien and Chris Maser.

4.0 The Commuter Rail Underpass Methodology

In order to improve multi-modal access into and out of the Inner Belt Core (IBC), the project team designed a Commuter Rail underpass to replace the Tubes. Currently the Tubes restrict pedestrian and bicycle access with small sidewalks, and due to the nature of the culvert design, large trucks have struck and damaged the Tubes. The proposed design is directed at remedying these problems while attempting to remain cost and time efficient. The first part of this chapter provides the reader with a section overviewing the components of a railway bridge. The second part of the chapter provides the methodology for this design process.

4.1 Overview of Railway Bridges

Most bridges can be separated into a superstructure and a substructure. The purpose of the superstructure is to collect the primary loads and distribute them down into the substructure, which in turn will dispense them into the supporting soil. The superstructure and substructure of a bridge are shown in the left part of Figure 8 below. Although the figure illustrates a highway bridge, the same principles apply to a train bridge. There are generally two types of superstructures used for railroad bridges, open bridge decks and ballasted decks (AREMA, 2003). Although more cost efficient, open bridge decks are not recommended for construction over roadways for a couple of reasons discussed below. The right side of Figure 8 illustrates a typical ballasted deck. The superstructure will therefore consist of tracks, ties, ballast, decking, and any supporting decking. The substructure will consist of retaining wall abutments and foundation footings.

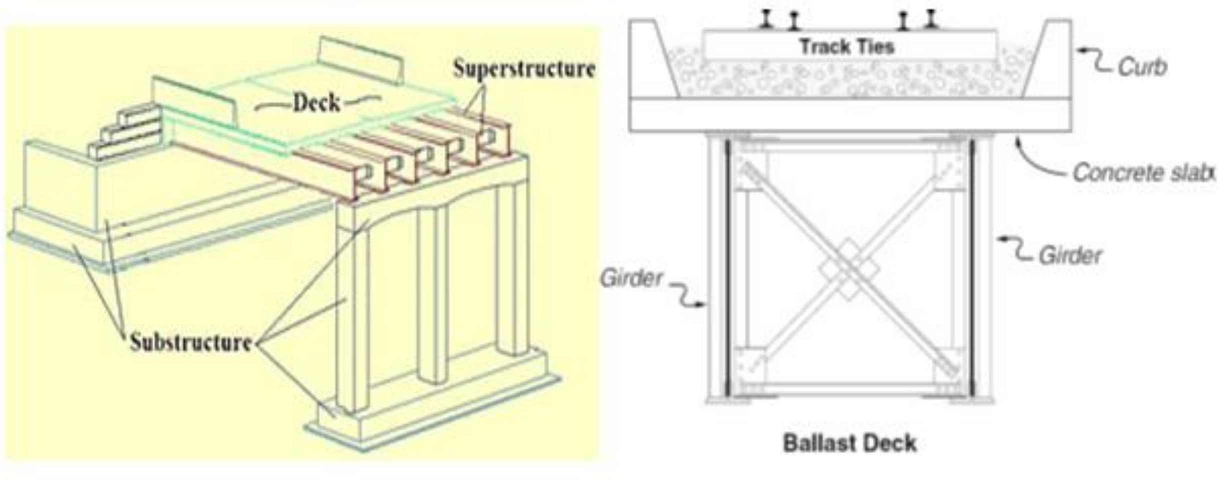

Figure 8 - Bridge Components (Oklahoma Bridge Tracker, 2009) and a Ballasted Railroad Deck (AREMA, 2003)

4.1.1 Superstructure

The primary members of the superstructure are the deck and the supporting members below the deck. Above the deck sits the ballast, which is usually a heavy material, such as gravel; the track ties; and the tracks (AREMA, 2003). The ballasted deck offers a consistent riding track onto and off of the bridge. A ballasted deck also provides sufficient drainage so that surface runoff is usually not a problem. When the train rides over the tracks, the track ties transmit the load by distributing it over their length. This load is than transmitted through the ballast and into the supporting deck.

4.1.1.1 Ballasted Deck

The ballasted deck is either made of a reinforced concrete slab or a steel plate (AREMA, 2010). A steel plate will have a lower depth than the concrete slab; however, the concrete slab is usually more cost efficient. Regardless of the decking used, the loads will be transmitted directly through the deck into the supporting members, or directly into the substructure if no supporting members are provided. For most concrete slabs, supporting members are required to ensure the concrete doesn't crack under high tensile, or flexural forces, as concrete is weak under these forces.

4.1.1.2 Supporting Members

For bridge design two common supporting members are stringers and girders. A stringer supports the deck longitudinally, while a girder supports the deck or stringers laterally (Ohio DOT, 2012). Although these members may vary in properties, they usually get their strength from steel. For short bridge spans, under fifty feet, AREMA recommends rolled or welded beams (AREMA, 2010). Rolled beams are steel beams that are rolled and produced in a steel factory generally into an I-shape, which improves performance under loading (French Creek Valley, 2011). Figure 9 below shows a cross section of a typical I-beam. Welded beams consist of short length beams that are welded together. Although steel beams are primarily used, other supporting members have recently been used in railroad construction.

Figure 9 - Cross section of an I-beam (Huddle Steel Buildings, 2011)

The Hybrid or, Hillman-Composite Beam, designed by John Hillman, is a beam that consists of a concrete arch tied on the bottom span of the arch by reinforcing steel (Angelo, 2008). The beam is then filled with low density foam and surrounded by a glass-fiber-reinforced plastic beam shell as can be seen in Figure 10. The beam optimizes the use of each member and is light weight. This beam was introduced in the early 21st century and is new to the market of bridge construction. Regardless of the supporting structure choice, it is designed and constructed to transmit the loading through the connecting members into the substructure.

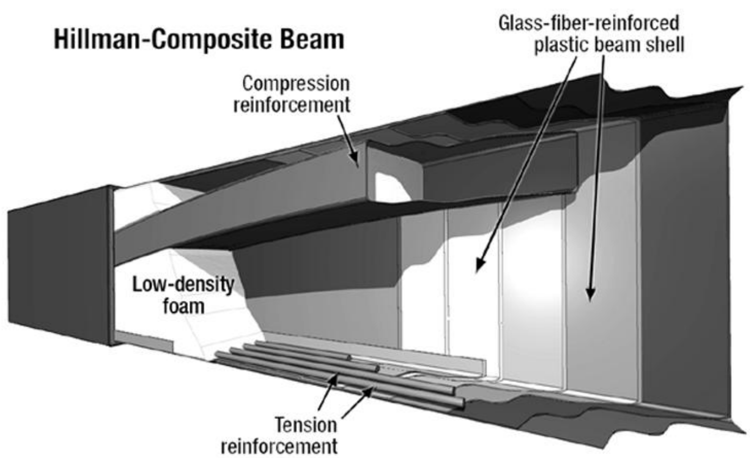

Figure 10 - Hillman-Composite Beam (Angelo, 2011)

4.1.2 Substructure

The substructure transmits the loads from the superstructure into the supporting soil. The substructure of a bridge can be broken up into a retaining wall abutment and the footing (U.S. DOT Federal Highway Administration, 2011). The retaining wall abutment transmits vertical loads from the superstructure as well as provides lateral support to the soil behind the wall. There are multiple ways a retaining wall can fail: material failure, overturning, sliding, soil bearing capacity, etc. Some common types of failures can be seen in Figure 11 below.

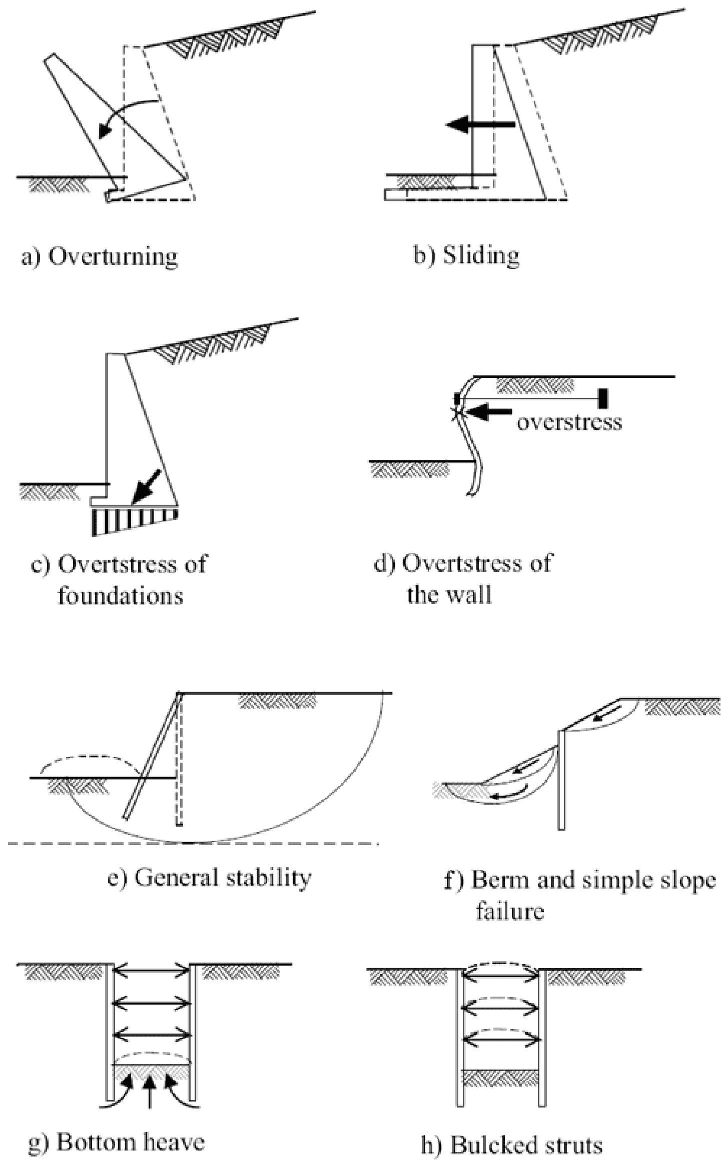

Figure 11 - Retaining Wall Failures (The Geological Society, 2011)

Retaining wall abutments are designed for the failures listed above as well as for the loading produced by the superstructure. There are three or four common types of retaining walls as can be seen in Figure 12 (Girard, 2012). The first type of retaining wall is a gravity retaining wall which offers strength against overturning due to the weight and size of the structure. Gravity walls are economically favorable up to ten feet tall. The semi-gravity wall is a thinner gravity wall which is reinforced on one side to provide tensile strength in the wall so it does not experience overstressing. The cantilever wall is smaller than the previous two and is therefore reinforced in more detail. The wall relies on the footing more than the previous two to resist overturning. This structure is generally economical for heights up to twenty-five feet. The final structure shown in the figure is a counterfort wall which is used for taller retaining walls. This wall is essentially a cantilever wall that is tied down periodically to prevent a failure due to overstressing.

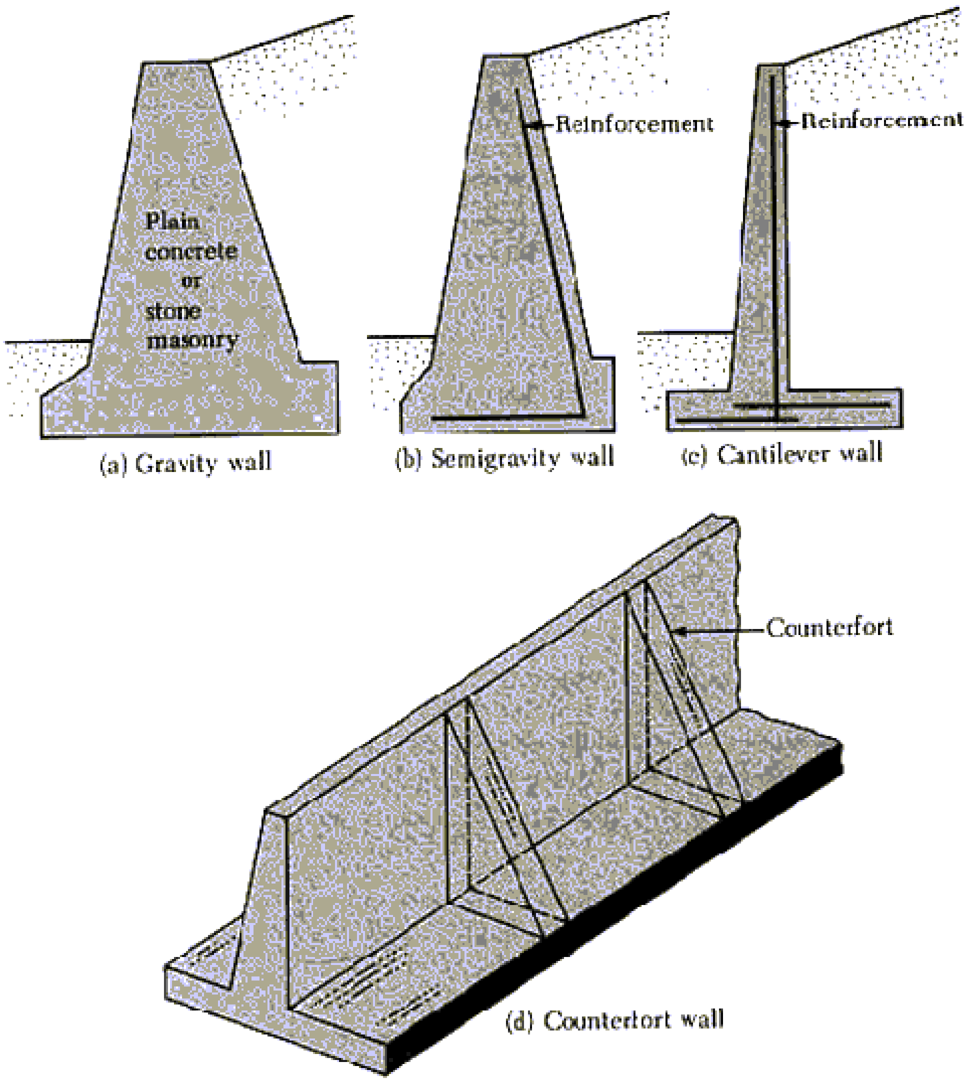

Figure 12 - Common Concrete Retaining walls (Girard, 2012)

The final part of the substructure design is the footing. Footings are designed to be larger than the abutment retaining wall above it in order to distribute the loads over a large enough area to limit soil stresses and settlement. Geotechnical investigations are required to determine the soil strength and settlement characteristics. If excessive settlement is predicted, a deep foundation will be required. A deep foundation will not be discussed in this section as it is outside of the scope of this report.

4.2 Methods

The team looked into multiple designs options and decided to select a pre-cast reinforced concrete deck supported by structural steel stringers for the superstructure and two reinforced concrete semi-gravity wall abutments for the substructure. During the design phase the team took cost and time into consideration and completed a cost and time estimate for the solution. Additionally, this project planned a detour route for vehicle traffic and the Commuter Rail to accommodate the demolition and new construction

4.2.1 Guidelines for the Design

The group considered multiple factors when selecting a bridge design. A reinforced concrete deck offered an economical favorability over a steel deck, and the selection of pre-cast, as opposed to cast-in-place concrete, allows for time efficient construction. Although concrete resists compressive stress quite efficiently, it is not as strong with tensile stresses. Even with the assistance of reinforcing steel, this deck could fail under loading without supporting members placed below the deck. To illustrate the large live loading expected, Figure 13 below shows the design live load according to AREMA (All units shown are in pounds).

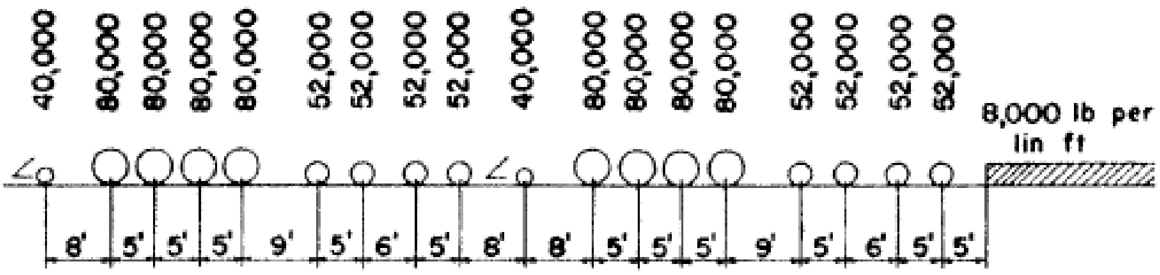

Figure 13 - Cooper E 80 Axle Load Diagram (AREMA, 2010b)

Design loads on the order of magnitude shown in Figure 13 are beyond the ability of the concrete deck to hold. To address the issue of needing a support for the deck, there were two options the group considered. One option would be to support the deck periodically with abutments, but in order to provide an open clearance under the bridge for multi-modal traffic, the team ruled this out. The second option was to support the deck with steel stringers and abutments located at the end of deck, which the team opted to do. The use of Hillman Composite Beams was considered; however, due to time restrictions and available information this alternative design was only completed at a preliminary level.

The most significant factors affecting the abutment design were the large surcharge forces created by the train, the reaction forces created by the loading of the bridge, the active effects of soil on the structure immediately after completion, and the amount of soil that would need to be excavated. Ultimately, the group chose a semi-gravity wall, as it offered some of the advantage of the deadweight present in a gravity wall to resist overturning moments, while offering the reinforced strength of the cantilever wall. With the selection of the substructure and superstructure, the design needs to comply with MBTA design guidelines, since the Commuter Rail Line is operated by them.

According to the MBTA's *Guide Specifications For Structural Design of Rapid Transit and Light Rail Structures*, the design of Commuter Rail structures and earth Retaining Structures shall follow the guidelines established in the *Manual for Railway Engineering* produced by the American Railway Engineering and Maintenance of Way Association (AREMA) except where amended by the MBTA (Fleming, 2005). The AREMA guidelines primarily directed the design with the exception of the deck thickness, where the design standards followed the provisions of the American Association of State and Highway Transportation Officials (AASHTO). Although AASHTO deals primarily with highway bridges, the recommended deck thickness was larger than AREMA's, so this was taken into consideration for an initial design assumption. The team only had access to certain editions of the AREMA Manual. For Seismic Design and Steel Structures the 2010 edition was referenced, and for Concrete structures and Foundations the 2000 edition was referenced. Load Factor Design (LFD) was implemented in a majority of the design, with the exception of the steel stringers where Allowable Stress Design (ASD) was the only available option in the edition of the *Manual For Railway Engineering*. The team chose to use LFD for the rest of the design as it is recommended over ASD by the MBTA (Fleming, 2005).

4.2.2 Superstructure

The first step in the superstructure design involved determining the design loads based on the assumptions presented in the AREMA manual and the parameters of the location. The design loads for the superstructure included: dead loads, live loads, impact loads, wind loads, longitudinal loads, snow loads, and rain loads. The design also considered earthquake loads; however, after a few initial calculations; the provisions of the AREMA manual determined that it wouldn't govern the design. This was due in part to the geometry of the proposed design and the magnitude of projected earthquakes in the greater Boston region. With design loads determined the group factored the design loads for LFD and determined the governing conditions for LFD and ASD, which for both designs included various combinations of dead loads, live loads, impact loads, longitudinal loads, and wind loads.

4.2.2.1 Design of Structural Steel Stringers

The team chose to design the steel stringers before the deck, in order to determine the number of members required and their spacing. AREMA has strict requirements for allowable stress in the beams and the deflection of these beams under live and impact loads, which controls their design (AREMA, 2010b). Thus small changes in the dead weight of the deck do not affect the live and impact load deflection, and will have a relatively small effect on the stress present in the beams. Another restricting factor is the roadway clearance. According to Massachusetts law, a low clearance bridge is defined as any bridge lower than thirteen and half feet, meaning any truck taller than this height is required to get a special permit to drive, thus limiting the depth of the beams (MassDOT, 2012).

During the layout and selection of the beams, the team initially chose six beams that would rest on the abutments in a pin-roller supported nature. According to AREMA, as long as the beams are spaced equally so as to be under the distributed live load and are subject to similar portions of the dead load, they may be assumed to support the same overall load (AREMA, 2010b). The design process for the structural steel stringers is detailed below in Figure 14.

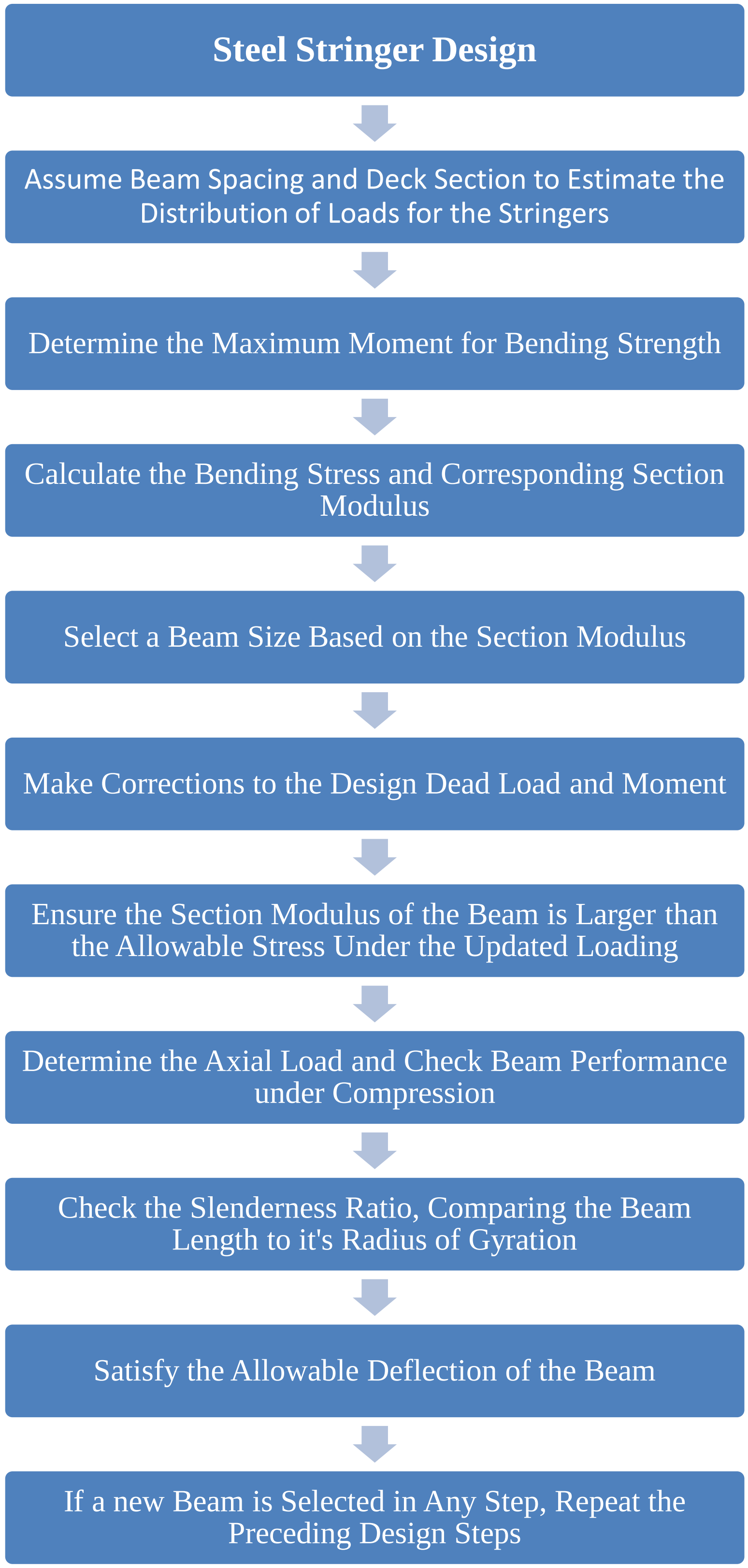

Figure 14- Steel Stringer Design Methodology

4.2.2.2 Design of the Reinforced Concrete Deck

The group chose to design a pre-cast reinforced concrete deck. A pre-cast reinforced concrete deck offers strength primarily under compressive bending forces, provides durability since it is cast in a controlled environment, and offers a quick erection time in field. As opposed to a cast-in-place deck, the pre-cast deck will allow for immediate loading from ballast and railway track, once it is attached to the steel stringers. In this stage of the design AASHTO enforced a stricter requirement for railway bridges, compared to AREMA, of an eight-inch minimum deck thickness. In order to be conservative the team opted to start with a deck thickness of nine inches. Succeeding this, the next phase involved determining the layout and amount of required reinforcement.

The steel stringers provide assumed continuous support for the deck in the longitudinal direction, however laterally there are only eight locations they provide support. This caused the reinforcement layout in the lateral direction to govern the design. The process for design meets the required strength as defined by LFD design, and the process can be seen below in Figure 15. During this design phase the team decided that the deck would extend a little beyond the steel stringers and be anchored into the substructure to provide a continuous load path. Although anchoring the deck lightens the design moments by providing a stiff connection, the group did not take this into consideration for any part of the pre-cast reinforced concrete deck design. Additionally the size of the panels would need to be equal to the width of the bridge or at least wide enough to extend over all of the stringers. If they do not do this, an adjustment to the design moments would be required to account for discrepancies in the lateral load path of the deck. The length of the panels can be left up to the company designing them and be sized so as to fit on a delivery truck.

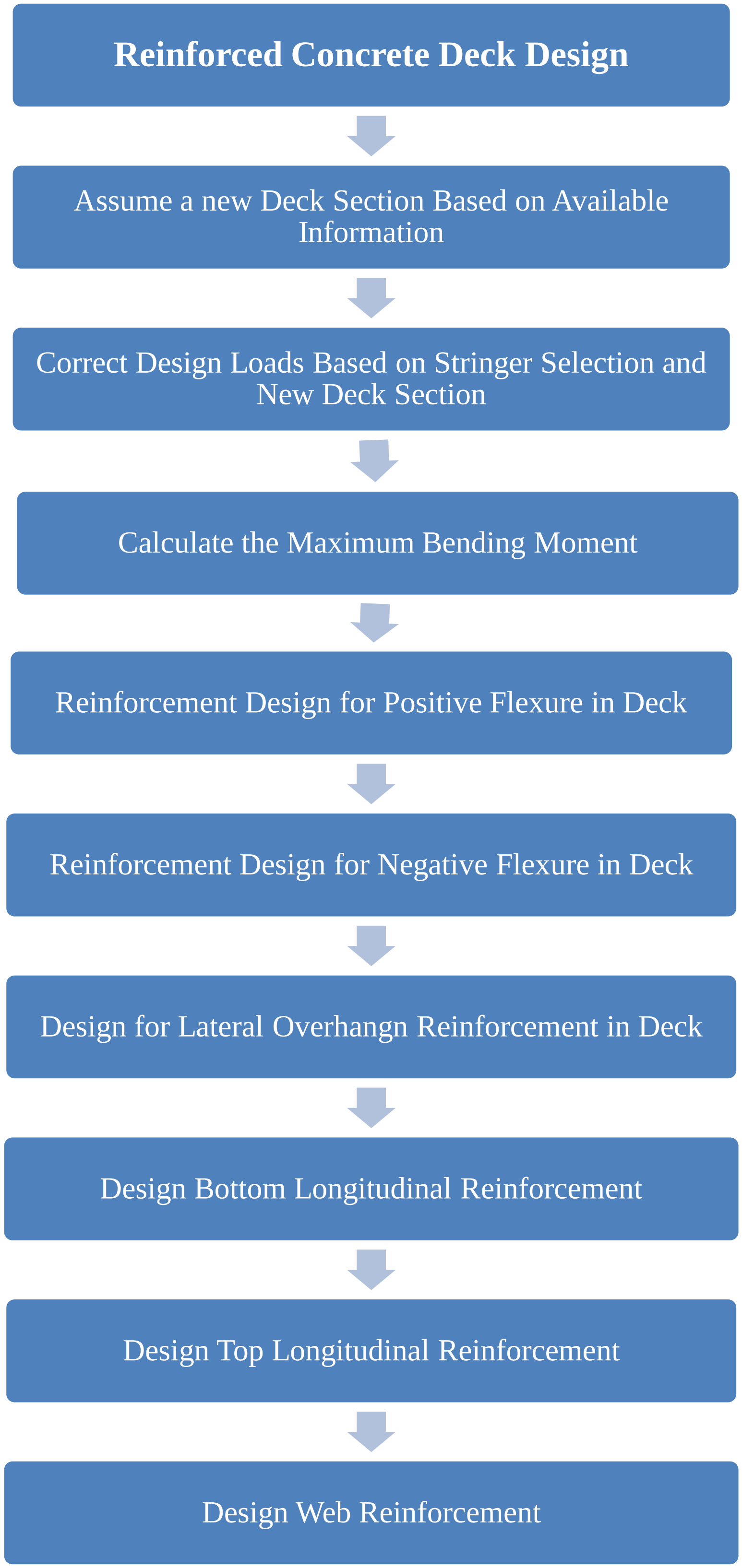

Figure 15 - Reinforced Concrete Deck Design

4.2.3 Substructure

The substructure design is a semi-gravity retaining wall abutment. A gravity wall is designed for low height retaining walls, ideally under ten feet, while a cantilever wall is generally designed for taller retaining walls, up to twenty five feet tall (Girard, 2012). For this design the retaining wall abutment needed to be a certain height so as to hold back the earth behind it while having a large enough cross-section so as to support the superstructure. A gravity wall wasn't feasible for this design due to the height requirements. A cantilever wall offered the benefits of reinforcing steel so its height could be extended; however, the team determined that a large cross-section would be required to support the superstructure. This led to the selection of a semi-gravity wall, which offered some of the benefits of both designs.

With this selection, reinforcing would only be required on the side of the wall closest to the backfill. This reinforcing will prevent the wall from failing in tension due to the large overturning moments caused by the backfill and surcharge created by the trains. The wall width will be sufficient to support the superstructure as well as contribute to the dead weight of the substructure, which helps to prevent overturning moments. Additionally, due to the geometry of the location, wing walls were not investigated as the width of the retaining walls take up a majority of the backfill area. If wing walls are needed they would provide support near the base of the wall. Finally, since the substructure is to be made of reinforced concrete, an LFD approach, similar to the concrete deck, was used. The process is detailed below in Figure 16.

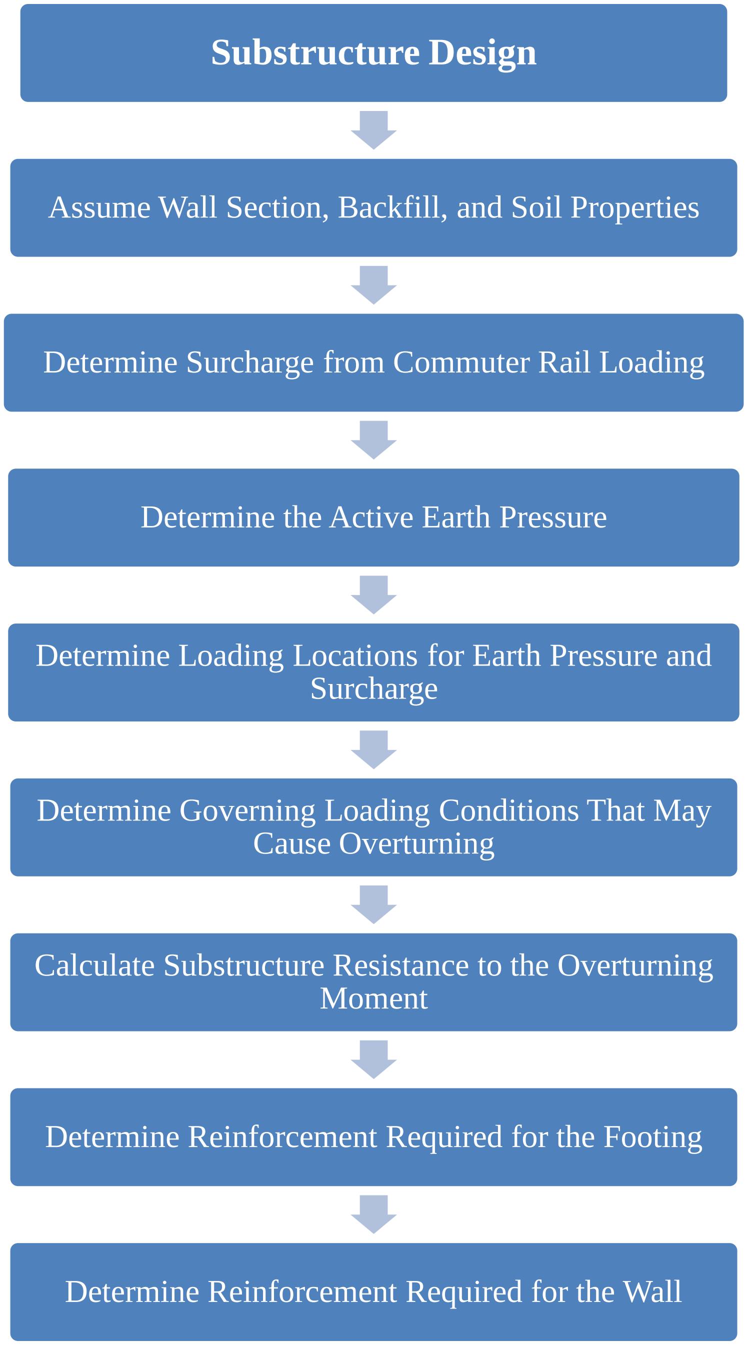

Figure 16 - Semi-Gravity Wall Design

Early in the design phase of a substructure the design team would need to survey the area in order to understand the various soil properties present and the location of the ground water table. A detailed site survey was not available to the group, so the team investigated the possible soil information for the area through the Massachusetts Geographical Information System (GIS).

According to GIS soil information of Middlesex County, a site survey of this part of Somerville is required due to the variety of soil properties that could be present (MassGIS, 2011). This restricted the design of the substructure and forced the team to make assumptions for the design.

Two significant assumptions were that the depth to the water table was sufficient to not affect the foundation substantially and that the soils were sandy, thus the footing would be a shallow foundation with a reasonably sized base. The presence of a high water table in close proximity to the foundation or clay-like soils could cause large settling, or create insufficient bearing capacity, and potentially suggest installing a deep foundation. If the soil information and the water table location are determined, the next step would be to determine the bearing capacity of the soil beneath the foundation, and ensure that excessive settling does not occur.

4.2.4 Bridge Connections

The final component of the bridge design was to connect the steel stringers, the deck, and the substructure together. The stringers and the deck will be welded together through metal plates. The stringers will rest on bearing pads bolted in on one end, so as to create a pin and roller support. On either side of the stringers' end there will be a small space present to allow for thermal expansion without inducing additional stresses on the beam. The bearing pads will be bolted in at the supports that do not have the beams bolted in. The concrete deck will be attached to the substructure through anchoring. This will require casting hardware into the deck section at the design factory. Although not a large component of the design these connections will allow the loads to transmit smoothly through the system and into the ground.

4.2.5 Cost and Time Estimation

Three components of any construction project are the scope, cost, and schedule. The scope of the work is already defined by what needs to be completed for removing and replacing the Commuter Rail Underpass. For the cost and scheduling, there are four major phases of the project that the team addressed: preparing the site, demoliting the existing structure, constructing the new overpass, and cleaning up the site/opening the bridge.

The *2009 R.S. Means Index* provided the information necessary to establish an initial cost estimate for the design. The *Index* provided the unit costs for material, labor, overhead, and profit. The group calculated the quantity of work that needed to be completed and multiplied these numbers by the unit costs provided. To keep track of the various parts of the project, the team used a Microsoft Excel spreadsheet. Not every aspect of the project appeared in the *Index*, so the group made unit cost estimates based on similar items found in the *Index*. After determination of these costs, the *Index* provided additional cost estimates for various parts of the project, such as quality control and city cost adjustment. The spreadsheet calculated a cost estimate which the group used to provide an inflation adjusted cost estimate for the present (2012), five years from now (2017), ten years from now (2022), and twenty years from now (2032). The inflation rate used for future values was 2.55%, which is the average inflation rate from 2000 up to 2011 (Current Annual Inflation Rate, 2012).

In addition to a cost estimate, the *2009 R.S. Means Index* displayed approximate productivity rates for a time estimate. These rates are listed as daily outputs, assuming standard eight hour work days. The cost estimate phase of the project determined the quantity of work that needed to be completed for each task, so by dividing that quantity of work by the expected daily output for the task, a time estimate for each work area was determined. Following this step the team determined an appropriate sequence of work that needed to be done and calculated the time estimate for completion of this project with the assistance of Microsoft Visio.

4.2.6 Construction Phase

The construction phase consists of three sections: vehicle traffic control, commuter train re-routing, and site layout. For vehicle traffic control, the group developed a plan to detour traffic through a fire entrance into the area. The team also presented two possibilities for re-routing the Commuter rail into and out of Boston. Finally the last section of this phase provides a simple scheme for delivery and storage of equipment and materials during construction.

Since the Tubes are the only point of vehicular access into the Inner Belt Core (IBC), the design provides a solution for traffic. Initially the construction phase involved staging the bridge to allow one lane to remain open for traffic; however, the team learned of a fire lane that is positioned on the Eastern side of the IBC (personal communication, Stephen Mackey, October 13, 2011). With this fire lane available the team developed a detouring plan around the construction site to allow for quicker construction of the project.

Although a straightforward solution became apparent for vehicle traffic, re-routing the train became a challenge. With a connection to North Station in Boston and a daily ridership of 12,893 passengers, the team determined shutting down the Commuter Rail line was not a feasible option (MBTA, 2010). Although multiple train lines run through North Station, none ride near the West Medford station. The first solution involved determining a bus route between West Medford and Boston. After running initial estimates for the volume of people and busses required, the team determined this would not be a wise course of action due to the large volume of people. The second option the team devised was to create a track detour from West of the Tubes around the site into the Commuter Rail Maintenance Facility and into North Station.

With the proposed vehicle and train detouring, the group developed a work space that is within the construction zone. The proposed detour around the site is far enough north and south of the site that sufficient space is available for storage of supplies, while still allowing access to the buildings within the site. Although planning detours is a necessary step in any construction project, the team focused more on the Commuter Rail Underpass Design and cost/time estimation of the project than they did on the Construction Phase.

5.0 A Framework for Urban Innovation

Chapter 5 establishes a framework for urban innovation that the project team used to shape redevelopment planning in the Inner Belt Core. Section 5.1 identifies the vision statement with key principles at the core of the framework. Section 5.2 discusses each of the key principles in the vision statement. Section 5.3 provides substantive specifications for the implementation of values into a design.

5.1 Vision Statement & Key Principles

With the MBTA Green Line Extension to Somerville, an economic opportunity exists to transform the light industrial Inner Belt Core neighborhood through transit-oriented, mixed-use redevelopment. This project provides a vision for such redevelopment based on seven key principles developed from works of *highest and best use* and *state-of-the-art design*:

1. Mixed-use development
2. Economic development
3. Connectivity, walkability, and modal variety
4. Identity and sense of place
5. Diversity and mixed incomes
6. Environmental sustainability
7. Livable community

Urban planning guidelines were used to develop design guidelines for each key principle, as well as a layout of infrastructural requirements to improve multimodal access. A new Commuter Rail

Underpass design is presented as a key infrastructural requirement. The final vision is a revitalized, groundbreaking commercial and residential Inner Belt Core.

5.2 Discussion of Key Principles

The key principles are discussed in terms of the *highest and best use* and *state of the art design*. The project goal stated previously supports the highest and best use for the area, as determined by the City of Somerville's Inner Belt/Brickbottom (IBBB) Plan and other local input. They also support state of the art design, which is founded on social, economic, and environmental sustainability. These two factors are applied to each of the seven key principles, delineated in Section 5.1, that support the goal. After the discussion of these principles, considerations are listed that need to be addressed in order to fulfill these principles when developing design guidelines.

Table 1, below, provides an overview of the key principles in terms of *highest and best use* and *state-of-the-art design.*

Table 1 Overview for Key Principles: *Highest and Best Use* and *State-of-the-Art Design*

Key Principle	*Highest and Best Use*	*State-of-the-Art Design*
Mixed-Use Development	• Heart of IBBB Plan for community • Linked to quality of life, economic development, and sustainability	• Key element of New Urbanism • Crucial ingredient of successful urban design • Need sufficient mix of activities
Economic Development	• Business-friendly environment • For financial self-sufficiency • To provide employment opportunities • Attract the creative class	• ASLA recommends balancing with other goals • Emphasize quality of life in a *state-of-the-art* mixed-use neighborhood for greatest benefit
Connectivity, Walkability, and Modal Variety	• Designing streets for people • Aspect of economic development and quality of life • Supports local businesses • Ensures easy flow of traffic into area, e.g. from GLX stop • Extending Community Path	• Meet goal of transit-oriented redevelopment • Meet LEED-ND standards for walkability and access • Meet Complete Streets standards for modal variety
Identity and Sense of Place	• Unique, distinct character • "Lively destination"	• Important to recruit companies • Need high density development
Diversity and Mixed Incomes	• Goal of Comprehensive Plan • Benefitting existing residents • Component of transit-oriented development	• Creative class prefers diverse areas • Equitable development in sustainability
Environmental Sustainability	• Popular for quality of life • Goal of Comprehensive Plan • Attract the creative class • Demonstrate Somerville's commitment to sustainability	• Environmental goals an aspect of *state-of-the-art design* • Meet LEED green goals • Land-use planning for sustainable development
Livable Community	• Creation of lively, social places • Public spaces, i.e. parks, plazas • Tied to quality of life, economic development	• Realize through mixed-use development • Provide places for positive social interaction

5.2.1 Mixed-Use Development

Highest and Best Use

Mixed-use development has long been championed as a crucial ingredient of successful urban design (Coupland, 1997; Jacobs, 1961). Mixed-use development is a cornerstone of the City of Somerville's vision for the Inner Belt/Brickbottom area. As previously noted, the City's Comprehensive plan calls for transformative, mixed-use development in order to promote economic growth. Mixed-use development and economic development, a major goal of redevelopment, are positively correlated. Mixed-use development has been favorably examined in a number of materials prepared by Goody Clancy et al. for the City (Goody Clancy et al.; 2001a, 2011b, 2011c).

Figure 17: Renovated Building in Old Town, Fort Collins, Colorado (Jacobs Carre, n.d.)

The City of Somerville seeks to achieve its mixed-use goals for the area through a mix of housing, retail, office, and research uses (Goody Clancy, 2011a). The IBBB Plan envisions that the IBC will likely see less residential development, as opportunities for large site developments like research parks and office buildings are easily applicable for the area (Goody Clancy, 2011c). Although residential is still an important part of the mix, research and office spaces will be a major economic force in the neighborhood, and should capitalize upon proximity to various universities and institutions.

State of the Art Design

Mixed-use development is key to the development theory of New Urbanism, which is at the heart of development theories emphasizing sustainability and quality of life. Institutions such as the American Society of Landscape Architects (ASLA) believe that communities should provide more options for housing, employment, and recreation (ASLA, 2008). Silberstein and Maser in *Land-Use Planning for Sustainable Development* promote the theories of New Urbanism and Traditional Neighborhood Development, which help form the foundation for transit-oriented, mixed-use development, and recommend paying particular attention to ensuring a sufficient mix of different activities, as this mix is sometimes lacking. Figure 17, above, displays a renovated mixed-use building with shops on the ground floor and residential uses on the upper floor.

Residential components of mixed-use development receive emphasis in urban planning theory. Silberstein and Maser recommend development with a population density high enough to provide a "critical mass" as a key step to strengthening the sense of place within a community. High density development will also have the economic benefit of supporting commercial activities within the development and making it a transportation destination (Silberstein & Maser, 2000). Similarly, Coupland in *Reclaiming the City* argues for emphasizing residential uses over large offices. While offices do support a number of smaller businesses simply by virtues of their workers for sustenance, they do not support the same community, culture, and public activities possible with supporting residential populations. Coupland makes this point by contrasting the City of London's sandwich shops, pubs and restaurants- which are only used at certain limited times during the day- with Westminister's robust cafe society (Coupland, 1997; MacCormac, 1987).

5.2.2 Economic Development

Highest and Best Use

A key aim of redevelopment in the Inner Belt Core is economic development, in the form of job creation and other economic measures. According to the Goody Clancy materials for the City's Inner Belt Plan, the City is looking for opportunities for:

Figure 18: Walkable street in Pitsford, New York (Burden, 2011)

· "Expanding Somerville's job base by leveraging its own high-quality workforce and connections to high-quality regional workforce; and

· Expanding Somerville's commercial tax revenues through expanded business activity (Goody Clancy, 2011a)"

These plans are in line with the goals listed in the City of Somerville's Comprehensive Plan regarding corridors, commercial squares and growth districts. The City seeks to develop financial self-sufficiency; to be a center of a wide range of diverse, high-quality jobs; and to create a business-friendly environment to bring a diverse mix of businesses to Somerville. The City also seeks to transform the Inner Belt (along with other key areas) into an "economic engine" through mixed-use, transit-oriented development (City of Somerville, MA, 2010).

The IBBB Plan targets knowledge/ innovation workers of the "creative class" who prefer urban areas (as discussed by Dunham-Jones and Williamson in *Retrofitting Suburbia*). Qualities that make today's places of choice to work and live are summarized: Main Streets, "social places," diversity, proximity to work, and social and environmental responsibility (Goody Clancy et al., 2011c).

State of the Art Design

The American Society of Landscape Architects (ASLA) states that communities are more livable when they encourage economic development. However this is not the sole goal; equal importance is placed on valuing ecological and cultural systems, promoting social equity, and creating places for positive social interaction. ASLA encourages livable communities to adopt sustainability and resource-efficiency, while growing employment, housing, and recreation opportunities; all with the goal of improving quality of life (ASLA, 2008). Thus planning for economic development must also make a variety of other living standards goals.

The authors of the highly regarded work *Retrofitting Suburbia* (named by ASLA as one of three key resources on sustainable urban development professional practice (ASLA, 2008)) theorize that mixed-use development that emphasizes quality of life is a more successful form of economic development than the traditional corporate campus (Dunham-Jones & Williamson, 2009). *LEED 2009 for Neighborhood Development Rating System*, explaining the importance of green neighborhood development, also affirms that the character of a neighborhood determines quality of life (Congress for New Urbanism et al., 2011). Such development is needed to attract workers from Richard Florida’s so-called creative class, who drive innovation and economic development (Dunham-Jones & Williamson, 2009). Figure 18, above, displays a walkable street in a LEED neighborhood bustling with pedestrians and shoppers.

5.2.3 Connectivity, Walkability, and Modal Variety

Highest and Best Use

Access and walkability are frequently cited as key aspects of redevelopment in the area in the Inner Belt/ Brickbottom (IBBB) Plan, and are key to mixed-use development. In fact, access and circulation infrastructure are named as specific challenges associated with redevelopment.

Figure 19: Walkable Street in Washington, D.C. (Soeharjono, 2011)

Strategic planning and urban design are important for creating walkability. The Plan calls for focus on pedestrian connections both within and beyond IBBB, more convenient vehicular connections, and extension of Somerville's pedestrian and bicycle path, the Community Path (Goody Clancy et al., 2011a). The Comprehensive Plan calls for "thoughtfully-designed, pedestrian-oriented mixed-use development." Connectivity is named as a goal for encouraging transit-oriented development and economic growth. Similarly, a human-scaled and walkable character is named in another goal (City of Somerville, MA, 2010).

State of the Art Design

Transit-Oriented Development (TOD) means not only connectivity to larger transit networks, but also being able to walk to shops and services, support local businesses and access daily needs without driving, and link trips to community uses such as schools and libraries (Zimbabwe, 2010). It involves streets and roads that are designed for people, not just for cars and active uses "fronting on the street" (Zimbabwe, 2010; Oregon TGM Program, n.d.). TOD also means accommodating all users. Thus TOD travel options must include bike and pedestrian connections in addition to a quality transit network and bus connections, as well as car sharing and shared parking (Zimbabwe, 2010). Figure 19, above, shows a walkable street in Washington, D.C. where pedestrians are welcomed with wide sidewalks, trees, and even beautiful buildings.

LEED 2009 for Neighborhood Development Rating System (LEED-ND) contains multiple guidelines relating to access and connectivity, such as external connectively, bicycle networks, intersection frequency, and compact development. LEED-ND also stresses the need for walkable mixed-use development. Development in separate, segregated land uses connected by highways results in undesirable environmental and health impacts in terms of greenhouse gas emissions and increased air pollution and related respiratory diseases. Furthermore, LEED-ND and many other references note that "automobile-oriented neighborhoods tend to be hostile to pedestrians and unsupportive of traditional mixed-use neighborhood centers." By locating residences and jobs near each other in walkable, mixed-use neighborhoods, automobile trips can be limited, and walking, bicycling, and public transportation can be encouraged for daily errands and commuting (Congress for New Urbanism et al., 2011).

Our vision calls for walkability in the IBC promoted by easy access to the Community Path, inviting human scale streetscapes, as well as safe pedestrian crossings. As aforementioned, a walkable neighborhood will allow residents to practicably commute and complete errands without the use of car, thereby reducing auto emissions and promoting healthy transportation practices.

5.2.4 Identity and Sense of Place

Figure 20 Warehouses Restored as Homes (Burden, 2011)

Highest and Best Use

The City of Somerville's Inner Belt/Brickbottom Plan emphasizes sense of place. It envisions using "distinguished streets, parks and architecture" to form a solid identity for the area (Goody Clancy et al., 2011a). Additionally, it says that future businesses sited in IBBB need an image for marketing and recruiting (Goody Clancy et al., 2011c). The City's Comprehensive Plan calls for "distinctive" development design that adds to its unique identity. It envisions strong neighborhood centers with widespread residential uses among "lively destinations." It also promotes preserving neighborhood character, in terms of buildings, patterns, and architecture (City of Somerville, MA, 2010). Figure 20, above, demonstrates a LEED neighborhood in which warehouses have been restored as houses, offering a unique take on the areas character. A W-ZHA analysis of the Inner Belt Core (IBC) named as a key challenge the fact that it currently has "absolutely no sense of place" (Goody Clancy et al., 2011c). Design for the areas will need to overcome this challenge.

State of the Art Design

Developing a local identity is in keeping with economic development strategies in modern urban planning thought. Dunham-Jones and Williamson, in *Retrofitting Suburbia*, name this an important quality, even above traditional economic development strategies: “cities that want to recruit leading companies need to focus their economic development activities more on improving their quality of life and sense of place than on the more conventional strategies of offering companies tax breaks or investing in silver bullets like stadiums” (Dunham-Jones and Williamson, 2009). Developing a quality sense of place is a cornerstone of the project team’s vision.

5.2.5 Diversity and Mixed Incomes

Highest and Best Use

Figure 21: Diversity can enhance a neighborhood’s identity (Cross, 2012)

Since the Inner Belt Core (IBC) is focused on the Green Line Extension, it can be considered to be transit-oriented, and thus diversity and mixed-income employment opportunities and residences should play a role. A City of Somerville presentation by the Director of the Center for Transit-Oriented Development linked on the website for Somerville’s Comprehensive Plan, discusses Transit-Oriented Development (TOD) in Somerville. It not only describes TOD in terms of transit opportunities, but also describes it as also encompassing an equitable development and mix of incomes (Zimbabwe, 2010). This goal is in keeping with the background of the area since one of the major justifications of the Green Line Extension has been a call for attention to Somerville’s environmental justice issues (STEP, 2011a, 2011b), and a displacement or exclusion of residents should be mitigated and prevented in keeping with social sustainability.

Promoting diversity and mixed incomes is also an existing goal in Somerville. Mixed-use, mixed income TOD that provides a mix of housing for "households of all types and from diverse social and economic groups" is a goal of the City's Comprehensive Plan. With new development, the Plan says the City should mitigate displacement of low and moderate income residents by preserving the amount of current affordable housing (City of Somerville, MA, 2010). The City already has taken steps for affordable housing. In 1991 an ordinance established the Somerville Affordable Housing Trust Fund (SAHTF) to benefit low to moderate-income households; SAHTF preserves and creates affordable rental and homeownership units (City of Somerville, MA, 2011a).

State of the Art Design

This key principle is also represents in works of *state-of-the-art design. LEED 2009 for Neighborhood Development Rating System* also calls for diversity and mixed income level: "Green neighborhood developments enable a wide variety of residents to be part of the community by including housing of varying types and price ranges." This source represents the latest thinking in green development. The rating categories of Mixed Income Diverse Communities and Affordable Housing permit developers or cities to earn up to six points total (Congress for New Urbanism et al., 2011). The Oregon Transportation and Growth Management (TGM) Program's *Commercial and Mixed Use Development Code Handbook* also supports this key principle. It recommends "a variety of housing choices, so that the young and old, singles and families, and those of varying economic ability may find places to live" (Oregon TGM Program, n.d.).

In the IBBB Plan for the City of Somerville, social responsibility is named as a key quality that makes a location popular for work and living (Goody Clancy et al., 2011c). In fact, in keeping with the latest in urban development theory expressed in *Retrofitting Suburbia*, the "creative class" that the City hopes to attract has been found to prefer areas that demonstrate tolerance for diversity (Dunham-Jones and Williamson, 2009; Goody Clancy et al., 2011c). Thus this key principle dovetails with those of economic development and livable community.

5.2.6 Environmental Sustainability

Figure 22: The Neighborhood Restaurant, Somerville (Pedersen, 2010)

Highest and Best Use

In the City of Somerville's IBBB Plan, environmental (in addition to social) responsibility is explicitly named as a quality that makes a location popular for work and living (Goody Clancy et al., 2011c).

Environmental quality is an explicit goal of the City's Comprehensive Plan (and healthy neighborhoods are emphasized as well) (City of Somerville, MA, 2010). Thus environmental values are a goal for new development in the Inner Belt Core.

Incorporating principles of environmental sustainability is in line with creating the development desired for the Inner Belt/Brickbottom area. The City of Somerville, in its vision prepared by Goody Clancy et al., seeks to bring a high-quality "creative class" of skilled, educated workers to the Inner Belt/Brickbottom area in order to boost investment (Goody Clancy et al.; 2011a, 2011b, 2011c). This creative class, discussed by Dunham-Jones and Williamson in *Retrofitting Suburbia*, increasingly is choosing jobs based on desirable locations, rather than moving based solely on the basis of jobs. Companies (and cities) who wish to attract these top workers thus cater to their preferences and work to increase quality of life (Dunham-Jones & Williamson, 2009). This creative class not only prefers urban areas, but also has been linked with valuing environmental responsibility (Cascio, 2005).

State of the Art Design

Environmental sustainability is now an accepted part of urban planning and design (ASLA, 2008; Congress for New Urbanism et al., 2011; Russ, 2009) Thomas H. Russ's *Site Planning and Design* guidebook devotes two chapters to sustainable design and green sites. Environmental considerations are driven by increased awareness of population growth, climate change, and wasteful land consumption, providing a background on the need for sustainability, concluding with the importance of energy and water conservation. Sustainable development must consider the local ecosystem, global ecosystem, and the future (Russ, 2009).

Environmentally responsible buildings and infrastructure are keys to creating green neighborhoods, as set forth in *LEED 2009 for Neighborhood Development Rating System*. LEED standards represent the industry consensus as they incorporate intensive input and are voted on by around 18,000 member organizations. (Russ, 2009). Green buildings and infrastructure have reduced impacts to climate, water, air quality, and natural resource consumption. Within the LEED-Neighborhood Development (LEED-ND) rating system category of "Green Infrastructure and Building" the prerequisites are certified green building, minimum building energy efficiency, minimum building water efficiency, and construction activity pollution prevention; other points can be won through practices such as stormwater management, on-site renewable energy sources, and green wastewater management (Congress for New Urbanism et al., 2011).

Silberstein and Maser's *Land-Use Planning for Sustainable Development* proposes such ideas for redesigning zoning ordinances for sustainable development, such as requiring a full range of innovation in technology in eco-parks. They also, as does Russ, recommend incentives in addition to requirements (Russ, 2009), citing places where developers were encouraged to improve quality of life in a community through affordable housing, parks, improvements in infrastructure, childcare facilities, and public art. Figure 22, above, of the Neighborhood Restaurant in Somerville, demonstrates how greenery can beautify an area, but even less visible environmental contributions can be publically valued. Incentives include not only traditional tax advantages, actual payment to landowners, allowing higher-than-usual building densities, etc., but also "rewards in the form of community recognition." Such community recognition could be given through awards presented by a city's official or unofficial Beautification Committee, which could recognize and publicize acts such as maintaining "a lovely flower garden," painting, or using appropriate signage (Silberstein & Maser, 2000). Similarly, the project team proposes that green practices could also be recognized by a Sustainability Committee. Environmental impact analysis and checklists for sustainability are also discussed and recommended.

5.2.7 Livable Community

Figure 23: Broome St, NY block party (Broome Street Block Party, 2008)

Highest and Best Use

The IBBB Plan envisions the area as a “great place to work, live, shop, play, learn.” While working and shopping are captured in economic development, living, playing, and learning can be thought of as different components of a livable community. An important part of meeting this goal is creating “social places,” named as one of the important qualities that make a place of choice to work and live (Goody Clancy et al., 2011c). Such social places could include parks or plazas, or even a pedestrian-only street as the lively street in Figure 23 shows. It is hoped that the challenges facing IBBB can be overcome by developing an urban design framework conducive to creating community (and attractive to the market) (Goody Clancy et al., 2011b).

State of the Art Design

Andy Coupland, in his oft-cited work *Reclaiming the City* frequently speaks of “vitality” when discussing development goals. He names this quality as a major benefit of and incentive for mixed-use development, with its concentration and diversity of activities (Coupland, 1987). Like influential Jane Jacobs, he places much value on creating a “lively, stimulating, and secure public realm” and promoting a sense of community within a neighborhood (Coupland, 1987; Jacobs, 1961).

This key principle also works to meet the goals of environmental responsible planning. Oregon Transportation Growth Management Program calls “both necessary and desirable” the creation of public spaces where people have the opportunity to formerly organize (e.g. a public outdoor market or festival), or informally gather for leisure/ social activity (Oregon TGM Program, n.d.). Russ’s *Site Planning and Design* guidebook additionally names designing to create or contribute to a sense of community as a guideline for green site planning and design (Russ, 2009).

The American Society of Landscape Architects (ASLA) published a key document called *Livable Communities*, from which the project team’s key principle was named (ASLA, 2008). The project team believes that ASLA’s concept encompasses Coupland’s idea of vitality, with its stress on providing places for “positive social interaction.” ASLA says communities’ livability is dependent on a number of factors, from education, housing, jobs and economic development, to health, physical environment, safety and security, and transportation. Coupland likewise agrees that multiple factors contribute to vitality (ASLA, 2008; Coupland, 1987).

5.3 Essentials of State of the Art Design

Section 5.3 takes the framework for urban innovation established in the previous chapter sections and discusses in detail the implementation of values into concrete planning measures. In this section the project team identifies and discusses the essentials of *state-of-the-art* design for urban redevelopment in terms of vision outcomes and specific corresponding design guidelines based on vision outcomes. This section names for the first time different practical applications of the key principles substantiated in the vision statement. In subsections corresponding to the seven key principles, thirty different main vision outcomes are discussed, as well as additional supporting ones that offer further detail for broad vision outcomes.

5.3.1 Mixed-Use Development

The overall vision for the Inner Belt Core is founded in terms of mixed-use development. Residential uses, discussed in this section, are a key component of mixed-use development. Various other outcomes of this key principle are discussed in the subsequent sections of different key principles.

Table 2 Mixed Use Development

Vision Outcome	Design Guideline	References
Residential Uses	Include a residential component equaling at least 30% of the project's total building square footage (not including parking structures)	LEED-ND pp. 5

At times a residential component has been de-emphasized in planning discussions for the Inner Belt Core. The Inner Belt/Brickbottom Plan mentions that the IBC will likely see less residential development, as opportunities for large site developments like research parks and office buildings are easily applicable for the area. Nevertheless, housing is named as a key aspect of overall redevelopment in the IBBB Plan, as it is an essential component of mixed-use development (Goody Clancy et al., 2011c). However, as discussed in Section 5.2, minimum residential densities are key to strengthening the sense of place within a community and providing support for culture and public activities (Silberstein & Maser, 2000; Coupland, 1997; MacCormac; 1987). Thus LEED-ND guidelines specify a minimum 30% of project building square footage be residential.

5.3.2 Economic Development

This section will discuss the following vision outcomes established to support economic development: local and regional jobs; retail, services/ amenities, office, and research/laboratory businesses.

Table 3 Economic Development

Vision Outcome	Design Guideline	References
Local and regional jobs	Prioritize economic development that creates jobs. Additionally prioritize economic development that benefits current Somerville residents	Goody Clancy et al., 2011c
Medium and small business	Encourage medium and small-scale businesses; prevent exclusive large-scale business development	Coupland, 1997; MacCormac, 1987
Retail	Encourage retail business, especially on the ground floor	Coupland, 1997; Goody Clancy et al., 2011c
Services	Encourage service uses as a component of business	Coupland, 1997; Goody Clancy et al., 2011c
Offices	Encourage office uses as a component of business	Coupland, 1997; Goody Clancy et al., 2011c
Research and Laboratories	Encourage research uses and laboratories as a component of business	OSPCD, 2011; Goody Clancy et al., 2011c

5.3.2.1 Local and regional jobs

As discussed in the vision statement, expanding the job base for area by drawing from the "high-quality" local and regional workforce is a key opportunity sought by the City of Somerville in the Inner Belt/Brickbottom (IBBB) Plan (Goody Clancy et al., 2011a). The City seeks to use development to create jobs, fiscal benefits, and other economic opportunities for Somerville residents (Goody Clancy et al., 2011c). Stephen Mackey, CEO of the Somerville Chamber of Commerce, has also conveyed the importance of job creation through IBBB development (personal communication, November 16, 2011).Thus economic development that provides numerous jobs should be prioritized over development that does not offer as many jobs. Additionally, development should offer employment opportunities specifically for the current residents of Somerville, not just create jobs that will largely be filled by workers who will need to relocate to the area and compete with available housing demand.

5.3.2.2 Medium and Small Business

Business is a critical component of the vision. In the Inner Belt/Brickbottom Plan the City of Somerville has established that expanding commercial tax revenue is needed (Goody Clancy, 2011a). The Somerville Chamber of Commerce has noted that the City is one of the most dependent cities in Massachusetts with lowest municipal budget per capita. They both envision a "self sufficient and fiscally sustainable" City that, through development associated with the Green Line Extension such as that in the Inner Belt Core, could become "less and less dependent on annual state aid" (City of Somerville, MA, 2010; Mackey, 2011). In order to ensure that business goals are met, a vision guideline will be established that dedicates an amount of development potential to business uses. Practices that create the business-friendly environment desired by the City should also be encouraged (City of Somerville, MA, 2010).

In terms of what types of business, Andy Coupland, author of *Reclaiming the City*, recommends against focusing solely on large office development, though it is typically seen as a goal of economic development. He asserts that large office development is not conducive to mixed-use development, saying that it "has proved one of the worst offenders of any building type in terms of producing dull, mono-functional areas." Smaller and medium-sized enterprises often may have more local connections than do larger ones, rely on local suppliers and distributors, and have local as well as regional trade as customers. "The accessibility of such enterprises to a local population has, a MacCormac points out, an immediate effect on the street." In order to create a sense of place in the IBC, development should include small and medium-sized enterprise and not exclusively large ones.

Larger offices do support a number of smaller businesses simply by virtues of their workers for sustenance. Nevertheless, they do not support the same community, culture, and public activities possible with supporting residential populations (Coupland, 1997; MacCormac; 1987). Thus residential uses are perhaps more key to an area's development than large offices.

5.3.2.3 Retail

This category of business plays a key role in mixed-use, economic development and can provide the highest rental returns (Coupland, 1997). It is also named as a vital aspect of redevelopment in planning for the IBBB, which will become a "great place to … shop" (Goody Clancy et al., 2011c). Andy Coupland names shopping as a central aspect of visitor attraction in mixed-use development in *Reclaiming the City*, and notes that a long tradition of mixed-use buildings with shops on the first floor and multiple residential units on upper floors goes back hundreds of years in Europe. Most retail activity is confined to the ground floor; only high-value shops take multiple floors (Coupland, 1997).

5.3.2.4 Services

Services and amenities are named as an important supporting aspect of development in IBBB in Goody Clancy's planning for the City of Somerville (Goody Clancy et al., 2011c). This type of business, like retail, is also stressed as a key piece of mixed-use development (Coupland 1997; Jacobs, 1961). Services such as small pedestrian-accessed city supermarkets contribute to the vitality of urban shopping streets (Coupland 1997).

5.3.2.5 Offices

Goody Clancy's market findings for IBBB stress office development, in addition to research/ laboratories. Professional, scientific, and technical employment is projected to increase by 2030 in Middlesex County, where Somerville is located. Furthermore, urban locations like IBBB are competitive for siting of "Class A Office/ Research." (Goody Clancy et al., 2011c). Coupland notes that large offices do support a number of smaller businesses simply through the need of their workers for sustenance, though these benefits are outweighed by other factors when an area is dominated solely by large office space. In typical "high street" development, offices (and apartments) are located above shops (Coupland, 1997).

5.3.2.6 Research and laboratories

Research and laboratories are a key target business of planning in the Inner Belt, as IBBB planning focuses on life science and institutional convergence. As discussed in the previous section, Goody Clancy's market findings for IBBB recommend research/ laboratories development (Goody Clancy et al., 2011c), and the Mayor's Office of Strategic Planning and Community Development also seeks life sciences and institutional convergence with nearby universities (OSPCD, 2011). Knowledge-based industries are desired in order to attracts skilled and educated workers, "and therefore significant investment" (Goody Clancy et al., 2011c).

5.3.3 Connectivity, Walkability, and Modal Variety

This section discusses various vision outcomes of connectivity, walkability, and modal variety: external connectivity; the density and building density of compact development; intersection frequency and internal connectivity of the urban grain; entryway spacing sidewalks, and reduced parking footprint with regard to walkability; vehicle service, including design speeds and on-street parking; bicycle services such as a path network and bicycle storage; and transit service.

Table 4 Connectivity, Walkability, and Modal Variety

Vision Outcome	Design Guideline	References
Compact Development: Density	Residential density (dwelling units/acre) of at least > 10 DU and as much as > 63 DU or greater and; Nonresidential density (floor-area ration) at least > 0.75 fAr and as much as > 3.0 fAr	LEED-ND pp. 53
Intersection Frequency	Min. 90 intersections/mi^2 as measured within a 1/2-mile distance of a continuous segment of the project boundary, equal to or greater than 25% of the project boundary, that is adjacent to previous development. (Existing external and internal intersections may be counted if they were not constructed or funded by the project developer within the past 10 years.)	LEED-ND pp. 1
External connectivity	Through streets or non-motorized ROW must intersect the project boundary at least every 600 ft on average, and at least every 800 ft; non-motorized ROW can be 20% of the total at most	LEED-ND pp. 1
Transit Service	At least 50% of dwelling units and nonresidential building entrances are within a 1/4 mile walk distance of bus stops, or within a 1/2 mile walk distance of bus rapid transit stops, or a Green Line station, and the transit service at those stops in aggregate meets the minimums identified in LEED-ND Table 1	LEED-ND pp. 3
Bicycle Network	An existing bicycle network of at least 5 continuous miles in length is within 1/4-mile bicycling distance of the project boundary or connects 10 diverse uses (Appendix) within 3 miles' bicycling distance from the project boundary	LEED-ND pp. 29

Bicycle Street Accommodation	At a minimum bicycles should be accommodated on-street in striped and marked bike lanes on 80' rights of way, and in shared lane facilities in smaller rights of way; Where bike lanes are adjacent to the curb, they should be allotted 4'-0"; More space should be allotted to bicycles where they travel adjacent to parked cars (5'-0");	ASMUD for the Public Realm, 2002; City of Boston, 2010
Bicycle Storage	a. Multiunit residential: At least one secure, enclosed bicycle storage space per occupant for 30% of the planned occupancy but no fewer than one per unit. Secure visitor bicycle racks on-site, with at least one bicycle space per ten dwelling units but no fewer than four spaces per project site. b. Retail: At least one secure, enclosed bicycle storage space per new retail worker for 10% of retail worker planned occupancy. Visitor or customer bicycle racks on-site, with at least one bicycle space per 5,000 square feet of retail space, but no fewer than one bicycle space per business or four bicycle spaces per project site, whichever is greater. At least one on-site shower with changing facility for any development with 100 or more new workers and at least one additional on-site shower with changing facility for every 150 new workers thereafter. c. Nonresidential other than retail: At least one secure, enclosed bicycle storage space per new occupant for 10% of planned occupancy. Visitor bicycle racks on-site with at least one bicycle space per 10,000 square feet of new commercial nonretail space but not fewer than four bicycle spaces per building. Same on-site shower and changing facility policy as in (b.)	LEED-ND pp. 29
Walkable Streets: Public Spaces	For 90% of new building frontage, a principal functional entry on the front façade faces a public space, such as a street, square, park, paseo, or plaza, but not a parking lot, and is connected to sidewalks or equivalent provisions for walking. The square, park, or plaza must be at least 50 feet wide at a point perpendicular to each entry.	LEED-ND pp. 41
Walkable Streets: Building Height Ratios	At least 15% of street frontage within and bordering the project has a minimum building height-to-street-width ratio of 1:3 - Nonmotorized rights-of-way may be counted toward the 15% requirement, but 100% of such spaces must have a minimum building-height-to-street-width ratio of 1:1. - Projects with bordering street frontage must meet only their proportional share of the height-to-width ratio - Street frontage is measured in linear feet. - Building height is measured to eaves or the top of the roof for a flat-roof structure, and street width is measured façade to façade. For building frontages with multiple	LEED-ND pp. 41

	heights, use the weighted average height of all frontage segments based on each LEED-ND pp.segment's height weighted by the segment's share of total building width. -Alleys and driveways are excluded.	
Walkable Streets: Sidewalks	Continuous sidewalks or equivalent all-weather provisions for walking are provided along both sides of 90% of streets or frontage within the project, including the project side of streets bordering the project. New sidewalks, whether adjacent to streets or not, must be at least 8 feet wide on retail or mixed-use blocks and at least 4 feet wide on all other blocks. Equivalent provisions for walking include woonerfs and allweather-surface footpaths. Alleys, driveways, and reconstructed existing sidewalks are excluded from these calculations.	LEED-ND pp. 41
Walkable Streets: Minimizing Garage and Service Bays	No more than 20% of the street frontages within the project are faced directly by garage and service bay openings.	LEED-ND pp. 41
Compact Development: Building Densities	For projects with existing and/or planned transit service (i.e., service with the funding commitments specified in SLL Prerequisite 1, Smart Location) that meets or exceeds the 2-point threshold in SLL Credit 3, Locations with Reduced Automobile Dependence, Option 1, build at the following densities, based on the walk distances to the transit service specified in SLL Credit 3: a. For residential components located within the walk distances: 12 or more dwelling units per acre of buildable land available for residential uses. b. For residential components falling outside the walk distances: 7 or more dwelling units per acre of buildable land available for residential uses. c. For nonresidential components located within the walk distances: 0.80 floor-area ratio (FAR) or greater of buildable land available for nonresidential uses. d. or nonresidential components falling outside the walk distances: 0.50 FAR or greater of buildable land available for nonresidential uses.	LEED-ND pp. 42
Internal Connectivity	Limit shifts in the visual axis along a route; employ straight streets.	Coupland, 1997; Hillier & Hanson, 1984
Design Speeds	75% of new residential-only streets within the project are designed for a target speed of no more than 20 mph. 70% of new nonresidential and/or mixed-use streets within the project are designed for a target speed of no more than 25 mph. A multiway boulevard, with travel lanes separated from access lanes by medians, may apply this requirement to its outer access lanes only (through-lanes are exempt), provided pedestrian crosswalks are installed across the boulevard at intervals no greater than 800 feet.	LEED-ND pp. 60

Reduced Parking Footprint	For new nonresidential buildings and multiunit residential buildings, either do not build new off-street parking lots, or locate all new off-street surface parking lots at the side or rear of buildings, leaving building frontages facing streets free of surface parking lots. Use no more than 20% of the total development footprint area for all new off-street surface parking facilities, with no individual surface parking lot larger than 2 acres. Provide bicycle parking and storage capacity to new buildings. Provide carpool and/or shared-use vehicle parking spaces equivalent to 10% of the total automobile parking for each nonresidential and mixed-use building on the site.	

5.3.3.1 External connectivity

The purpose of external connectivity is to encourage flow of people between the Inner Belt Core and the surrounding neighborhoods. Goody Clancy, identifying challenges for redevelopment in the IBC for the City of Somerville, goes so far as to say that the Inner Belt Core (IBC) is simply “not transit-oriented” since it is “ too far” from the nearest Green Line Extension station as Washington Street (Goody Clancy et al., 2011c). A design guideline will establish a minimum number of connections to the surrounding neighborhoods outside the project area.

5.3.3.2 Compact development:

High density is a part of mixed-use development, crucial to maintaining an “intensity of activity” in streets. This quality is a function of both the quantity of people and the mix of uses (Coupland, 1997).

5.3.3.2.1 Residential density

Urban planning leaders such as Jacobs recommend a minimum number of dwelling units per acre in order to maintain urban vitality (Coupland, 1997; Jacobs, 1961). A design guideline will thus be set for this vision outcome.

5.3.3.2.2 Building density

A density of uses is important as well. Larger blocks may “provide an acceptable urban environment” if building have the ability to be sub-divided vertically, and have smaller-scale retail and commercial uses are present at ground level. The opposite is true as well; single-use buildings can provide vitality if they are small enough to “offer a variety of attractions through their collective diversity” (Coupland, 1997).

5.3.3.3 Urban grain

Urban grain refers to the size of the urban block and the subdivision of the block (Coupland, 1997). The Inner Belt Core is currently considered to have poor road infrastructure. This problem can be overcome with the implementation of a street grid (Goody Clancy et al., 2011c).

5.3.3.3.1 Intersection frequency

Permeability is a key aspect of mixed-use; development should take place in small blocks that allow for pedestrian choice, though blocks that are too small may dilute pedestrian flow. City blocks should be kept small and the associated street grid preserved in order to increase the "potential variety of urban forms and the likelihood of a diverse use pattern in any area" (Coupland, 1997). Durham-Jones and Williamson likewise argue that block size is the most important factor in walkability (Durham-Jones & Williamson, 2009), highlighting a need to block size recommendations.

5.3.3.3.2 Internal connectivity

While permeability and small blocks are important, those qualities are less important than limiting shifts in the visual axis along a route, as Hillier and Hanson propose, since this can be a more important factor than distance in determining pedestrian activity (Coupland, 1997; Hillier & Hanson, 1984). A design guideline will be set accordingly.

5.3.3.4 Walkability

Walkability is a characteristic of the ease with which pedestrians can move between destinations within an area. In addition to enabling pedestrian transportation, as discussed in the previous section (Urban Grain), it importantly contributes to sense of place. Efficient, strategic use of space also determines walkability- for example street set-backs, entryway spacing, sidewalks, and reduced parking footprint.

5.3.3.4.1 Street set backs

The closer a building facade is fronted to the sidewalk and street, the more approachable the building becomes for pedestrians (Coupland, 1997). Close proximity to the sidewalk makes structures appear more welcoming and permeable. This approach to building to sidewalk proximity tends to decrease vehicles speeds as well. Design guidelines regarding acceptable setbacks will be established.

5.3.3.4.2 Entryway spacing

Spacing of entryways also contributes to overall walkability. LEED-ND standards call for a minimum frequency of entryways along non-residential or mixed-use buildings and blocks (Congress for New Urbanism et al., 2009). Guidelines such as those established by the City of Somerville for Assembly Square Mixed Use District (ASMUD) should be applied in the Inner Belt Core as well (City of Somerville, 2004).

5.3.3.4.3 Sidewalks

Sidewalks are necessary for considering all users in street design and increasing, as they are key to encouraging walking and providing pedestrian safety. They are especially beneficial when lined with trees and set apart from traffic with a buffer. Street furnishings further increase walkability and add to the sense of place conveyed by streets (Durham-Jones & Williamson, 2009; Russ, 2009). Guidelines, based on those in the widely endorsed complete streets initiatives and specified in LEED-ND, should ensure continuous sidewalks along both sides of a set very high percentage of streets and/or frontage, as well as specify minimum sidewalk widths for new development (Congress for New Urbanism, et al. 2011).

5.3.3.4.4 Reduced parking footprint

This step is important for emphasizing the pedestrian orientation of projects. It also has positive environmental and health benefits (Congress for New Urbanism et al., 2011). Similarly, oversupplying parking should be avoided (Durham-Jones & Williamson, 2009 Oregon TGM Program, n.d.). Guidelines should control total project surface area dedicated to parking lots, and on-street parking should be strictly controlled, as demonstrated by LEED-ND standards.

5.3.3.5 Vehicle service

Vehicle service is an important component of transportation vision outcomes in the Inner Belt Core (IBC). Though alternative transportation modes are encouraged, motor vehicles are nevertheless a fundamental transportation mode and require incorporation in planning.

5.3.3.5.1 Design speeds

Speed limits should be set to make areas both pedestrian-friendly and pedestrian-safe. LEED-ND guidelines recommend a range of 20-25 mph for this purpose (Congress for New Urbanism et al., 2011). Speed limits should not simply be posted, but also supported through traffic-calming techniques that facilitate pedestrian street crossings such as narrow streets or streets with medians (Durham-Jones & Williamson, 2009).

5.3.3.5.2 On-street and other parking

While reduced parking footprints are one vision outcome, parking is still a necessary part of development, and on-street parking plays an important role, though LEED-ND standards encourage it to be located on side streets rather than main streets (Congress for New Urbanism et al., 2011). Guidelines should establish suitable locations and proportional quantities of parking.

5.3.3.6 Bicycle service

Bicycles represent another key transportation mode needing corresponding infrastructure as part of the multi-modal network. Bicycle services have two key components: the path network and bicycle storage. These elements allow transportation directly between destinations, as well as between different modes such as transit and foot travel. This vision outcome also supports public health (Congress for New Urbanism et al., 2011).

5.3.3.6.1 Path network

A network of bicycle and pedestrian paths promotes both bicycle and overall transportation efficiency since it provides bicyclists a range of options and simultaneously provides an alternative to motor vehicles, reducing vehicle miles travelled (VMT). Guidelines concerning minimum recommended network distances and connection variety are needed to ensure a sufficiently large network of diverse destinations (Congress for New Urbanism et al., 2011).

5.3.3.6.2 Storage

Bicycle storage is the second component of this transportation mode. Designated storage at key residential, retail, and other locations facilitates bicycle and multi-modal trips. Guidelines should establish minimum storage capacities for certain development types.

5.3.3.7 Transit service

Transit is an important alternative to driving. Transportation planning includes identification of nearby transit stops and provision of key improvements such as shelter, seating, and bicycle facilities (Congress for New Urbanism et al., 2011). The IBBB Plan also calls for “enhanced transit access” as a key improvement identified for the area (Goody Clancy et al., 2011a).

5.3.4 Identity and Sense of Place

This section describes design approaches that orient the IBC towards a pedestrian friendly and distinctive identity. Vision outcomes include building aesthetics, street set-backs, building height ratios, retail storefronts and entryways, tree-lined and shaded streets, and the Boston skyline.

Table 5 Identity and Sense of Place

Vision Outcome	Design Guideline	References
Facades: Set Backs	a. At least 80% of the total linear feet of street-facing building façades in the project is no more than 25 feet from the property line. b. At least 50% of the total linear feet of street-facing building façades in the project is no more than 18 feet from the property line. c. At least 50% of the total linear feet of mixed-use and nonresidential street-facing building façades in the project is within 1 foot of a sidewalk or equivalent provision for walking.	LEED-ND pp. 49
Facades: Entryways	d. Functional entries to the buildings occur at an average of 75 feet or less along nonresidential or mixed-use buildings or blocks. e. Functional entries to the buildings occur at an average buildings or blocks (items d and e are cumulative).	LEED-ND pp. 49
Facades: Storefronts	f. All ground-level retail, service, and trade uses that face a public space have clear glass on at least 60% of their façades between 3 and 8 feet above grade. g. If a façade extends along a sidewalk, no more than 40% of its length or 50 feet, whichever is less, is blank (without doors or windows). h. Any ground-level retail, service, or trade windows must be kept visible (unshuttered) at night; this must be stipulated in covenants, conditions, and restrictions (CC&R) or other binding documents	LEED-ND pp. 50

Facades: On-Street Parking	i. On-street parking is provided on a minimum of 70% of both sides of all new and existing streets, including the project side of bordering streets. The percentage of on-street parking is calculated by dividing the length of street designated for parking by the total length of the curb along each street, including curb cuts, driveways, and intersection radii. Space within the parking lane that is occupied by corner bulb-outs (within 24 feet of an intersection), transit stops, and motorcycle or bicycle parking may be counted as designated for parking in this calculation. Woonerfs are not considered streets for this subsection.	LEED-ND pp. 50
Facades: Sidewalks	j. Continuous sidewalks or equivalent provisions for walking are available along both sides of all streets within the project, including the project side of streets bordering the project. New sidewalks, whether adjacent to streets or not, must be at least 10 feet wide on retail or mixed-use blocks and at least 5 feet wide on all other blocks. Equivalent provisions for walking include woonerfs and all-weather-surface footpaths at least 5 feet wide. Note that these requirements specify wider sidewalks than required by NPD Prerequisite 1, Walkable Streets.	LEED-ND pp. 51
Facades: Ground-floor retail	l. In nonresidential or mixed-use projects, 50% or more of the total number of office buildings include groundfloor retail along 60% of the length of the street-level façade; 100% of mixed-use buildings include groundfloor retail, live-work spaces, and/or ground-floor dwelling units along at least 60% of the street-level façade; and all businesses and/or other community services on the ground floor are accessible directly from sidewalks along a public space, such as a street, square, paseo, or plaza, but not a parking lot.	LEED-ND pp. 52

5.3.4.1 Building aesthetics

Buildings' impressions, entrances, windows, and details such as lighting and signs should all contribute to "a human scale" that invites pedestrian traffic (Durham-Jones & Williamson, 2009). Furthermore, unified strategies for designing and retrofitting structures tend to architecturally express an identity. The particular identity employed for the IBC area should follow particular guidelines in order to foster an architecture style in the IBC that communicates a degree of walkability (Coupland, 1997).

5.3.4.1.1 Building height ratios

Urban scale refers to building height to street width ratios (or controlling height with architectural measures such as hiding extra height in an attic story) (Coupland, 1997). Unified building heights appear aesthetically pleasing in the peripheral vision of pedestrians. Architecture becomes more coherent for pedestrians when building height and street width are linked, as the otherwise chaotic built environment becomes an "outdoor room" (Coupland, 1997; Dunham-Jones, E. & Williamson, J. 2009). The project team's design will establish a ratio for building height to street width in order to achieve that outcome.

5.3.4.1.2 Retail storefronts & entryways

Establishing retail storefronts on the first floor of buildings is an effective method for promoting pedestrian traffic. Potential patrons permeate through adjacent and nearby retail storefronts to accomplish errands on foot. This retail activity can populate sidewalks and streets with a significant amount of pedestrians. Streets that concentrate pedestrians typically promote safety because of a heightened degree of mutual concern. Retail storefronts also utilize glass displays that reciprocate attention inwards from the street and outwards towards the street. (Coupland, 1997). In turn, retail zoning will be established as a particular guideline to promote walkability and safety. Reducing the number of garages and service bays exposed to the street will be an important outcome of the IBC mixed-use development design.

5.3.4.2 Tree-lined and shaded streets

Design guidelines that specify the inclusion of trees juxtaposed between streets and pedestrian areas tend to decrease vehicle speeds and increase safety for pedestrians. Additionally, in warmer weather, pedestrians feel more at ease when protected from the sun (Dunham-Jones, E. & Williamson, J. 2009).

5.3.4.3 Boston Skyline

The view from the Inner Belt Core is highlighted as an asset for the area (Goody Clancy et al., 2011c). This vision outcome calls to utilize views of Boston's neighboring skyline, which is visible at ground level in most of the IBC, and will highlight additional elements to develop a sense of place.

5.3.5 Diversity and Mixed Incomes

This section contains three vision outcomes: mixed-use neighborhood centers, affordable residential housing, and mixed income diverse communities.

Table 6 Diversity and Mixed Incomes

Vision Outcome	Design Guideline	References
Mixed-Use Neighborhood Centers	At least 4 diverse uses and 20% occupancy of total square footage and as much as greater than 19 diverse uses and 50% occupancy of total square footage.	LEED-ND pp. 55
Mixed Income Diverse Communities	A Simpson Diversity Index score of at least over 0.5 and as much as greater than 0.7.	LEED-ND pp. 57
Affordable Housing	Include a proportion of new rental and/or for-sale dwelling units priced for households earning below the area median income (AMI). Rental units must be maintained at affordable levels for a minimum of 15 years. Existing dwelling units are exempt from requirement calculations. Table 3 contains various desirable thresholds.	LEED-ND pp. 58
Affordable Residential	Include a residential component equaling at least 30% of the project's total building square footage (exclusive of parking structures), and locate and/or design the project such that the geographic center (or boundary if the project exceeds 500 acres) is within 1/2-mile walk distance of existing full-time-equivalent jobs whose number is equal to or greater than the number of dwelling units in the project; and satisfy the requirements necessary to earn at least one point under NPD Credit 4, Mixed Income Diverse Communities, Option 2, Affordable Housing.	LEED-ND pp. 31

5.3.5.1 Mixed-use neighborhood centers

Pedestrian traffic creates more social capital (Dunham-Jones, E. & Williamson, J. 2009). Small to medium sized developments allow for a greater density of uses and often promote pedestrian trips and community relationships. Centralizing a diverse range of enterprises makes services more accessible and efficient to get to. Conversely, large single-use development of buildings stifles the efficiency of commuting and completing errands. The design for the IBC will maximize the aforementioned concept of a mixed-use neighborhood center.

5.3.5.2 Affordable residential housing

Concern for environmental justice populations was cited as one of the primary motivations behind the GLX. The elevated amounts of automobile emissions from increasing vehicle usage and Somerville's lack of rail transit centers motivated politicians and activists to bring attention to the GLX (Somerville Transportation Equity Partnership, 2009). The displacement of citizens originally intended to benefit from the GLX would be an unjust planning strategy. It is crucial that the mixed-use development strategy used in the IBC incorporates affordable housing that benefits those most adversely affected by environmental justice issues. The Somerville Affordable Housing Trust Fund (SAHTF) for low to moderate-income households contains policies relating to this design guideline (City of Somerville, MA, 2011a).

5.3.5.3 Mixed income diverse communities

One of major aims of mixed-use development is to promote social, environmental, and economic sustainability. Along with affordable housing for low and medium-income families, employment for these families is also needed. Presentation materials of the City of Somerville's website describe transit-oriented development as equitable development for a mix of incomes (Zimbabwe, 2010).

Design guidelines for this vision outcome are based on the Simpson Diversity Index. This index calculates the probability that “any two randomly selected dwelling units in a project will be of a different type.” The score is calculated by the equation: Score = $1- \Sigma (n/N)^2$, where n is the total number of dwelling units in a single category, and N is the total number of dwelling units in all categories (Congress for New Urbanism et al., 2011).

5.3.6 Environmental Sustainability

This section contains a number of different vision outcomes that comprise environmental sustainability: green buildings, tree-lined and shaded streets, local food production, green construction practices, existing building reuse, green water practices, green energy practices, solid waste management, and light pollution prevention.

Table 7 Environmental Sustainability

Vision Outcome	Design Guideline	References
Tree-Lined and Shaded Streets	-Design and build the project to provide street trees on both sides of at least 60% of new and existing streets within the project and on the project side of bordering streets, between the vehicle travel way and walkway, at intervals averaging no more than 40 feet (excluding driveways and utility vaults). -Trees or other structures provide shade over at least 40% of the length of sidewalks on streets within or contiguous to the project. Trees must provide shade within ten years of landscape installation. Use the estimated crown diameter (the width of the shade if the sun is directly above the tree) to calculate the shaded area.	LEED-ND pp. 75
Green Buildings	-Design, construct, or retrofit one whole building within the project to be certified through a LEED building certification process or other accredited green building rating system (see Appendix B). Alternatively design, construct, or retrofit a percentage of the total project building square footage, beyond the prerequisite requirement, to be certified under one of the LEED green building rating systems listed above or through an accredited green building rating system.	LEED-ND pp. 77

Minimum Energy Efficiency	-The following requirement applies to 90% of the building floor area (rounded up to the next whole building) of all nonresidential buildings, mixed-use buildings, and multiunit residential buildings four stories or more constructed as part of the project or undergoing major renovations as part of the project. New buildings must demonstrate an average 10% improvement over ANSI/ASHRAE/IESNA Standard 90.1–2007 (with errata but without addenda). Buildings undergoing major renovations must demonstrate an average 5% improvement over ANSI/ASHRAE/IESNA Standard 90.1–2007 (these standards refer to lighting efficiency with regard to overall building design and technological advancements). Projects must document building energy efficiency. -For new single-family residential buildings and new multiunit residential buildings three stories or fewer, 90% of the buildings must meet ENERGY STAR or equivalent criteria. Projects may demonstrate compliance with ENERGY STAR criteria through the prescriptive requirements of a Builder Option Package, the Home Energy Rating System (HERS) index, or a combination of the two.	LEED-ND pp. 78
Minimum Water Efficiency	-For nonresidential buildings, mixed-use buildings, and multifamily residential buildings four stories or more: Indoor water usage in new buildings and buildings undergoing major renovations as part of the project must be an average 20% less than in baseline buildings. The baseline usage is based on the requirements of the Energy Policy Act of 1992 and subsequent rulings by the Department of Energy, the requirements of the Energy Policy Act of 2005, and the fixture performance standards in the 2006 editions of the Uniform Plumbing Code or International Plumbing Code as to fixture performance. Calculations are based on estimated occupant usage and include only the following fixtures and fixture fittings (as applicable to the project scope): water closets (toilets), urinals, lavatory faucets, showers, kitchen sink faucets, and pre-rinse spray valves. -For new single-family residential buildings and new multiunit residential buildings three stories or fewer, 90% of buildings must use a combination of fixtures that would earn 3 points under LEED for Homes 2008 WE Credit 3, Indoor Water Use.	LEED-ND pp. 80

Construction activity pollution prevention	Create and implement an erosion and sedimentation control plan for all new construction activities associated with the project. The plan must incorporate practices such as phasing, seeding, grading, mulching, filter socks, stabilized site entrances, preservation of existing vegetation, and other best management practices (BMPs) to control erosion and sedimentation in runoff from the entire project site during construction. The plan must list the BMPs employed and describe how they accomplish the following objectives: a. Prevent loss of soil during construction by stormwater runoff and/or wind erosion, including but not limited to stockpiling of topsoil for reuse. b. Prevent sedimentation of any affected stormwater conveyance systems or receiving streams. c. Prevent polluting the air with dust and particulate matter. The erosion and sedimentation control plan must describe how the project team will do the following: a. Preserve vegetation and mark clearing limits. b. Establish and delineate construction access. c. Control flow rates. d. Install sediment controls. e. Stabilize soils. f. Protect slopes. g. Protect drain inlets. h. Stabilize channels and outlets. i. Control pollutants. j. Control dewatering. k. Maintain the BMPs. l. Manage the erosion and sedimentation control plan. The BMPs must be selected from the Washington State Department of Ecology's Stormwater Management Manual for Western Washington, Volume II, Construction Stormwater Pollution Prevention (2005 edition), or a locally approved equivalent, whichever is more stringent, and must comply with all federal, state, and local erosion and sedimentation control regulations.	LEED-ND pp. 82

Water Efficient Landscaping	Reduce water consumption for outdoor landscape irrigation by 50% from a calculated midsummer baseline case. Reductions may be attributed to any combination of the following strategies, among others: a. Plant species, plant density, and microclimate factor. b. Irrigation efficiency. c. Use of captured rainwater. d. Use of recycled wastewater. e. Use of water treated and conveyed by a public agency specifically for nonpotable uses. f. Use of other nonpotable water sources, such as stormwater, air-conditioning condensate, and foundation drain water. Projects with no new or existing landscape irrigation requirements automatically meet the credit requirements. Groundwater seepage that is pumped away from the immediate vicinity of buildings slabs and foundations can be used for landscape irrigation and meet the intent of this credit. However, it must be demonstrated that doing so does not affect site stormwater management systems.	LEED-ND pp. 88
Existing Building Reuse	Reuse the existing habitable building stock, achieving the greater of the following two benchmarks (based on surface area): a. 50% of one existing building structure (including structural floor and roof decking) and envelope (including exterior skin and framing but excluding window assemblies and nonstructural roofing material). b. 20% of the total existing building stock (including structure and envelope, as defined above). Hazardous materials that are remediated as a part of the project scope must be excluded from the calculations. Also: Do not demolish any historic buildings, or portions thereof, or alter any cultural landscapes as part of the project. An exception is granted only if such action has been approved by an appropriate review body. For buildings listed locally, approval must be granted by the local historic preservation review board, or equivalent. For buildings listed in a state register or in the National Register of Historic Places, approval must appear in a programmatic agreement with the State Historic Preservation Office.	LEED-ND pp. 89
Minimized Site Disturbance in Design and Construction	Development footprint on previously developed land: Locate 100% of the development footprint on areas that are previously developed and for which 100% of the construction impact zone is previously developed. For existing trees over a certain size that should be preserved (as indicated in the LEED-ND	LEED-ND pp. 91

	specifications), develop a plan, in consultation with and approved by an ISA-certified arborist, for the health of the trees, including fertilization and pruning, and for their protection during construction.	
Stormwater Management	-Implement a comprehensive stormwater management plan for the project that retains on-site, through infiltration, evapotranspiration, and/or reuse, the rainfall volumes listed in Table 1. Rainfall volume is based on the project's development footprint, any other areas that have been graded so as to be effectively impervious, and any pollution-generating pervious surfaces, such as landscaping, that will receive treatments of fertilizers or pesticides. -Select BMPs from the Washington State Department of Ecology's Stormwater management Manual for Western Washington, Volume V, Run off Treatment (2005 edition), or locally approved equivalent, whichever is more stringent. If the BMPs are comparable in stringency, choose BMPs that are most appropriate to the project site and region. BMPs must also comply with all federal, state, and local regulations. For stormwater reuse systems not on a combined stormwater and sewer system, the total water reused for indoor use must not exceed 90% of the average annual rainfall. Stormwater BMPs (except cisterns) must be designed to drain down within 72 hours.	LEED-ND pp. 93

<table>
<tr>
<td>Heat Island Reduction</td>
<td>Nonroof measures:

Use any combination of the following strategies for 50% of the nonroof site hardscape (including roads, sidewalks, courtyards, parking lots, parking structures, and driveways):
a. Provide shade from open structures, such as those supporting solar photovoltaic panels, canopied walkways, and vine pergolas, all with a solar reflectance index (SRI) of at least 29.
b. Use paving materials with an SRI of at least 29.
c. Install an open-grid pavement system that is at least 50% pervious.
d. Provide shade from tree canopy (within ten years of landscape installation).
High-reflectance and vegetated roofs:
Use roofing materials that have an SRI equal to or greater than the values in table below for a minimum of 75% of the roof area of all new buildings within the project; or install a vegetated (“green”) roof for at least 50% of the roof area of all new buildings within the project. Combinations of SRI compliant and vegetated roofs can be used provided they satisfy the equation below.

<table>
<tr><th>Roof slope</th><th>SRI</th></tr>
<tr><td>Low (≤ 2:12)</td><td>78</td></tr>
<tr><td>Steep (> 2:12)</td><td>29</td></tr>
</table>

$$\frac{\text{Area of Nonroof Measures}}{0.5} + \frac{\text{Area of SRI Roof}}{0.75} + \frac{\text{Area of Vegetated Roof}}{0.5} \geq \text{Total Site Hardscape Area} + \text{Total Roof Area}$$
</td>
<td>LEED-ND pp. 95</td>
</tr>
<tr>
<td>Solar Orientation</td>
<td>-Locate the project on existing blocks or design and orient the project such that 75% or more of the blocks have one axis within plus or minus 15 degrees of geographical east-west, and the east-west lengths of those blocks are at least as long as the north-south lengths of the blocks.
Or
-Design and orient 75% or more of the project’s total building square footage (excluding existing buildings) such that one axis of each qualifying building is at least 1.5 times longer than the other, and the longer axis is within 15 degrees of geographical east-west. The length-to-width ratio applies only to walls enclosing conditioned spaces; walls enclosing unconditioned spaces, such as garages, arcades, or porches, cannot contribute to credit</td>
<td>LEED-ND pp. 96</td>
</tr>
</table>

	achievement. The surface area of equator-facing vertical surfaces and slopes of roofs of buildings counting toward credit achievement must not be more than 25% shaded at the time of initial occupancy, measured at noon on the winter solstice.	
On-Site Renewable Energy Sources	Incorporate on-site nonpolluting renewable energy generation, such as solar, wind, geothermal, small-scale or micro hydroelectric, and/or biomass, with production capacity of at least 5% and as much as 20% or more of the project's annual electrical and thermal energy cost (exclusive of existing buildings).	LEED-ND pp. 98
District Heating and Cooling	-Incorporate a district heating and/or cooling system for space conditioning and/or water heating of new buildings (at least two buildings total) such that at least 80% of the project's annual heating and/or cooling consumption is provided by the district plant. Single-family residential buildings and existing buildings of any type may be excluded from the calculation. -Each system component that is addressed by ANSI/ASHRAE/IESNA Standard 90.1–2007 must have an overall efficiency performance at least 10% better than that specified by the standard's prescriptive requirements. Additionally, annual district pumping energy consumption that exceeds 2.5% of the annual thermal energy output of the heating and cooling plant (with 1 kWh of electricity equal to 3,413 Btus) must be offset by increases in the component's efficiency beyond the specified 10% improvement. Combined heat and power (CHP) district systems can achieve this credit by demonstrating equivalent performance.	LEED-ND pp. 99
Infrastructure Energy Efficiency	Design, purchase, or work with the municipality to install all new infrastructure, including but not limited to traffic lights, street lights, and water and wastewater pumps, to achieve a 15% annual energy reduction below an estimated baseline energy use for this infrastructure. The baseline is calculated with the assumed use of lowest first-cost infrastructure items.	LEED-ND pp. 100
Wastewater Management	Design and construct the project to retain on-site at least 25% and as much as 50% or more of the average annual wastewater generated by the project (exclusive of existing buildings), and reuse that wastewater to replace potable water. Provide on-site treatment to a quality required by state and local regulations for the proposed reuse. The percentage of wastewater diverted and reused is calculated by determining the total wastewater flow using the design case after the GIB Prerequisite 3 calculations, and determining how much of that volume is reused on-site.	LEED-ND pp. 101
Recycled Content in Infrastructure	Use materials for new infrastructure such that the sum of postconsumer recycled content, in-place reclaimed materials, and one-half of the preconsumer recycled content constitutes at least 50% of the total mass of infrastructure materials. Count materials in all of the following infrastructure items as applicable to the project: a. Roadways, parking lots, sidewalks, unit paving, and curbs.	LEED-ND pp. 102

	b. Water retention tanks and vaults. c. Base and subbase materials for the above. d. Stormwater, sanitary sewer, steam energy distribution, and water piping. Recycled content is defined in accordance with ISO/IEC 14021, Environmental labels and declaration, Self-declared environmental claims (Type II environmental labeling).	
Solid Waste Management Infrastructure	a. Include as part of the project at least one recycling or reuse station, available to all project occupants, dedicated to the separation, collection, and storage of materials for recycling; or locate the project in a local government jurisdiction that provides recycling services. The recyclable materials must include, at a minimum, paper, corrugated cardboard, glass, plastics and metals. b. Include as part of the project at least one drop-off point (with a plan for postcollection disposal), available to all project occupants, for potentially hazardous office or household wastes; or locate the project in a local government jurisdiction that provides collection services. Examples of potentially hazardous wastes include paints, solvents, oil, and batteries. c. Include as part of the project at least one compost station or location (with plan for postcollection disposal), available to all project occupants, dedicated to the collection and composting of food and yard wastes; or locate the project in a local government jurisdiction that provides composting services. d. On every mixed-use or nonresidential block or at least every 800 feet, whichever is shorter, include recycling containers adjacent to other receptacles or recycling containers integrated into the design of the receptacle. e. Recycle and/or salvage at least 50% of nonhazardous construction and demolition debris. Develop and implement a construction waste management plan that, at a minimum, identifies the materials to be diverted from disposal and specifies whether the materials will be stored on-site or commingled. Excavated soil and land-clearing debris do not contribute to this credit. Calculations can be done by weight or volume but must be consistent throughout.	LEED-ND pp. 103
Light Pollution Reduction	In residential areas, at least 50% of the external luminaires must have fixture-integrated lighting controls that use motion sensors to reduce light levels by at least 50% when no activity has been detected for 15 minutes. AND In all shared areas, install automatic controls that turn off exterior lighting when sufficient daylight is available and when the lighting is not required during nighttime hours; these lights must meet the total exterior lighting power allowance requirements.. AND Document which lighting zone or zones describe the project, and for all shared areas, follow	LEED-ND pp. 104

	the LEED-ND requirements. If two or more different zones border the project, use the most stringent uplight requirements, and use light trespass requirements for the adjacent zone. Roadway lighting that is part of the project must meet the requirements for the appropriate zone. For illuminance generated from a single luminaire placed at the intersection of a private vehicular driveway and public roadway accessing the site, project teams may use the centerline of the public roadway as the site boundary for a length of two times the driveway width centered at the centerline of the driveway when complying with the trespass requirements. Compliance with the light trespass requirements may alternatively be met by using only luminaires that comply with Table 4 ratings for backlight and glare. AND Stipulate covenants, conditions, and restrictions (CC&R) or other binding documents to require continued adherence to the requirements.	
Local Food Production	-Establish covenants, conditions, and restrictions (CC&R) or other forms of deed restrictions which state that the growing of produce is not prohibited in project areas, including greenhouses, any portion of residential front, rear, or side yards; or balconies, patios, or rooftops. Greenhouses but not gardens may be prohibited in front yards that face the street. -Dedicate permanent and viable growing space and/or related facilities (such as greenhouses) within the project according to the square footage areas specified in Table 1 (exclusive of existing dwellings). Provide solar access, fencing, watering systems, garden bed enhancements (such as raised beds), secure storage space for tools, and pedestrian access for these spaces. Ensure that the spaces are owned and managed by an entity that includes occupants of the project in its decision making, such as a community group, homeowners' association, or public body. Project density (DU/acre) Growing space (sf/DU) > 7 and ≤14 200 > 14 and ≤ 22 100 > 22 and ≤ 28 80 > 28 and ≤ 35 70 > 35 60 DU = dwelling unit; sf = square feet. Established community gardens outside the project boundary but within a 1/2 mile walk distance of the project's geographic center can satisfy this option if the garden otherwise meets all of the option requirements. -Purchase shares in a community-supported agriculture (CSA) program located within 150	LEED-ND pp. 73

	miles of the project site for at least 80% of dwelling units within the project (exclusive of existing dwelling units) for two years, beginning with each dwelling unit's occupancy until the 80% threshold is reached. Shares must be delivered to a point within 1/2 mile of the project's geographic center on a regular schedule not less than twice per month at least four months of the year. -Locate the project's geographic center within a 1/2-mile walk distance of an existing or planned farmers' market that is open or will operate at least once weekly for at least five months annually. Farmers' market vendors may sell only items grown within 150 miles of the project site. A planned farmers' market must have firm commitments from farmers and vendors that the market will meet all the above requirements and be in full operation by the time of 50% occupancy of the project's total square footage.	

5.3.6.1 Green buildings

Buildings in environmentally sustainable development should reflect the values of the overall development. LEED-ND requires that at least one building in the development area be LEED certified in order to encourage other buildings to also adopt green practices. A guideline could also be established for a minimum amount of LEED certified square footage as a percent of the total project (Congress for New Urbanism, et al., 2011). Green building practices could be highlighted as part of the area's identity and be used to market Inner Belt/ Brickbottom (IBBB) as an area of innovation.

5.3.6.2 Tree-lined and shaded streets

Trees offer tangible environmental quality benefits, as well as contribute to an area's aesthetics and identify. Trees and shade promote healthy, environmentally-friendly pedestrian and bicyclist transportation alternatives to driving, as well as decrease speeding. They reduce a number of undesirable urban problems such as poor air quality, the urban heat island effect, and heightened cooling loads in buildings (Congress for New Urbanism, et al., 2011). The inclusion of trees in urban areas also improves quality of life by beautifying an area and fostering psychological wellbeing, reducing stress, increasing immunity of the body, improving productivity, promoting healing, and even reducing crime (Maller et al., 2008). In fact, the university faculty who authored *Healthy Parks, Healthy People* go so far as to say of greenery that "the positive effects on human health, particularly in urban environments, cannot be over-stated" (Maller et al., 2008). Guidelines should set minimum amounts of trees and/or shading.

5.3.6.3 Local food production

This vision outcome is supports environmental sustainability through community farms and gardens, improved nutrition, support of small-scale agriculture, and reduced reliance upon and less negative effects from large-scale agriculture. Furthermore, according to LEED-ND, local food production "support[s] local economic development that increases the economic value and production of farmlands and community gardens" (Congress for New Urbanism et al., 2011). This vision outcome can be enabled through the establishment of deed restrictions that specifically state that the growing of produce is not prohibited. Community gardens, shares in community-supported agriculture, and proximity to farmer's markets are all examples of other potential areas for which to establish guidelines (Congress for New Urbanism et al., 2011).

5.3.6.4 Green construction practices

It follows that environmentally-sensitive buildings be constructed with environmentally sensitive practices. Green construction practices include pollution prevention, minimizing site disturbance, and use of recycled content.

5.3.6.4.1 Construction activity pollution prevention

The intent of this vision outcome is simply to, for the sake of environmental quality, manage soil erosion, waterway sedimentation, and airborne dust generation associated with construction. LEED-ND requires the development and implementation of an erosion and sedimentation plan (Congress for New Urbanism et al., 2011).

5.3.6.4.2 Minimized site disturbance in design and construction

This vision outcome refers to the preservation of existing noninvasive trees, native plants, and pervious surfaces, as suggested by LEED-ND. This can be done by containing development to previously developed land or establishing portions of project land to remain undisturbed. Particular care should be taken to identify and preserve those trees that are in good or excellent condition, considered heritage or champion trees, or with diameters larger than 6 inches at breast height (Congress for New Urbanism et al., 2011).

5.3.6.4.3 Recycled content in infrastructure

Using recycled and reclaimed materials in infrastructure construction furthers environmental sustainability by reducing the negative environmental impact from extracting and processing virgin resources. LEED-ND guidelines suggest at least 50% of materials be composed of post-consumer recycled content, in-place recycled materials, and pre-consumer recycled content (with only half credit for the latter). Infrastructure materials include pavement, water storage chambers, base and sub-base materials, and piping for various types of water (Congress for New Urbanism et al., 2011).

5.3.6.5 Existing building reuse

While construction of green buildings is encouraged, reuse of existing buildings is an important environmental practice for conserving resources, reducing waste, and reducing various negative effects from the manufacturing and transport of materials for new buildings. LEED-ND establishes requirements for reuse of set percentages of existing buildings intended for occupancy (residences, offices, etc.) Additionally, historic buildings and cultural landscapes should be preserved (Congress for New Urbanism et al., 2011). Planning should incorporate these guidelines into rules for redevelopment in the project area.

5.3.6.6 Green water practices

Various techniques that comprise green water practices include minimum water efficiency, wastewater management, stormwater management, and water efficient landscaping.

5.3.6.6.1 Minimum water efficiency

Efficient use of water is an important aspect of environmental sustainability. LEED-ND recommends the use of a variety of techniques and technologies to achieve a reduction of 20% less water use than in baseline buildings (Congress for New Urbanism et al., 2011). Minimum water efficiency standards could be established via regulatory and non-regulatory land use controls.

5.3.6.6.2 Wastewater management

Management of wastewater, too, is a basic environmental consideration for pollution reduction and reusing water. Wastewater guidelines recommended by LEED-ND include retaining at least a quarter of the project's wastewater on-site, reusing retained wastewater to replace potable water, and treating wastewater on-site (Congress for New Urbanism et al., 2011).

5.3.6.6.3 Stormwater management

Stormwater management is a standard environmental consideration concerning water. It is intended to essentially preserve water quality and control water quantity. Additionally it can support the natural hydrological cycle through groundwater recharge via low impact development practices. Guidelines suggested in LEED-ND include retention of stormwater on site through the use of stringent best management practices (BMPs) (Congress for New Urbanism et al., 2011).

5.3.6.6.4 Water efficient landscaping

The significance of this vision outcome is to conserve water by either entirely eliminating the use of potable water and key natural water resources for landscape irrigation, or at the very least limiting this use. An example guideline required by LEED-ND is the reduction of water consumption at least 50% from a (calculated) midsummer baseline case. Reductions can be achieved through means such as plant species and planting factors, irrigation efficiency, and use of captured rainwater and recycled water (Congress for New Urbanism et al., 2011).

5.3.6.7 Green energy practices

Both the Green Line Extension and Community Path extension projects are aiming to foster greater sustainable transportation and lifestyle practices in Somerville. Building design as a practice in itself also has the ability to further the community's sustainability goals. Opportunities arise to ensure that new buildings maintain a commitment to sustainability in their design.

This vision outcome emphasizes the Inner Belt's opportunity to seize sustainable building design during redevelopment. Proposed structures in the Inner Belt should consider using LEED guidelines for building design and construction because they correspond with LEED neighborhood design guidelines. LEED certified structures would complement a mixed-use development steered by LEED neighborhood design. Achieving LEED building design and construction status can be used as a marketing strategy to draw interest from certain demographics (Cascio, J. 2005). A joint effort to build LEED certified buildings in the area could result in the IBBB becoming recognized for its commitment to environmental sustainability. The following building design criteria have been selected as design and construction priorities to maximize energy efficiency.

5.3.6.7.1 Minimum energy efficiency

Maximizing the energy efficiency of local buildings is one the most effective ways for a community to reduce its contributions to air, water, and land pollution. Energy costs noticeably decrease as well. New buildings in the Inner Belt should consider using LEED building and construction guidelines to achieve minimum energy efficiency. These guidelines can apply to mixed-use buildings. Eligibility is specific to building size by floor area and requires interested parties to produce a design that illustrates how minimum energy efficiency guidelines are achieved (Congress for New Urbanism et al., 2011).

5.3.6.7.2 Heat island reduction

Many of the materials used in urban infrastructure, especially rooftops and pavement, absorb daytime solar energy. This residual heating effect disrupts wildlife, creates greater demand for cooling energy on warm days, and often makes the urban environment unpleasant in warmer seasons. To decrease energy demand for cooling and maximize the environmental potential for both humans and wildlife, LEED guidelines suggest selecting materials based on solar reflective index (SRI).

A higher SRI rating equates to a material more desirable for reducing the heat island effect because it retains less solar energy. Paving materials with an SRI of at least 29 are considered adequate, although higher SRI ratings are encouraged. Installing of vegetated "green" roofs and landscaping that provides shade are other measures that help reduce the heat island effect substantially. (Congress for New Urbanism et al., 2011).

5.3.6.7.3 Solar orientation

Energy efficiency can be increased in buildings when they are oriented to optimally seize solar light. Specifically, this can be accomplished by angling a building, or even better the entire street grid, no more than 15 degrees from the geographic east-west axis. Buildings should have a minimum length ratio of 1:1.5, where the longer side is oriented within 15 degrees of the east-west axis. The surface area of equator-facing vertical surfaces on the longer sides and slopes of roofs of buildings must be no more than 25% shaded (measured at noon on the winter solstice) Congress for New Urbanism et al., 2011).

5.3.6.7.4 On-site renewable energy sources

LEED design and construction guidelines will grant certification points for incorporating on-site renewable energy sources. On-site renewable energy reduces the demand for off-site energy, a percentage of which was likely produced by non-renewable means. They also help attain energy security and often reduce the financial burden of purchasing energy. On-site sources of solar, wind, geothermal, and biomass energy are all acceptable means to facilitate on-site energy (Congress for New Urbanism et al., 2011).

5.3.6.7.5 District heating and cooling

Future developments should consider utilizing preexisting or initiating district heating/cooling system. District heating distributes steam to a connected system, providing buildings with a source of steam energy for hot water and heating. In a similar practice, district cooling utilizes an outside source to act as a heat sink, effectively removing heat energy from building interiors. District heating and cooling practices have been shown to reduce carbon footprints and are one of the various ways to facilitate LEED building certification (Congress for New Urbanism et al., 2011).

5.3.6.7.6 Infrastructure energy efficiency

Miscellaneous infrastructure like wastewater pumps and traffic lights that are energy efficient can be selected to reduce overall energy usage in a community. LEED guidelines suggest a 15% annual energy reduction compared to the lowest first-cost infrastructure items (Congress for New Urbanism et al., 2011).

5.3.6.8 Solid waste management infrastructure

Solid waste creates a need for landfill space. A great deal of waste is generated from infrastructure projects, many of which are envisioned to occur in the Inner Belt area. To address this issue, LEED neighborhood guidelines call for the reuse of at least half of nonhazardous debris resulting from construction and demolition (Congress for New Urbanism et al., 2011).

As the living and working population is likely to increase, the Inner Belt area will need enhanced practices in waste management. To reduce the demand for landfill space, many communities work with municipal services to manage recycling efforts. LEED neighborhood design guidelines suggest working with existing municipal recycling services to reduce solid waste volume in landfills (Congress for New Urbanism et al., 2011).

If utilizing an existing municipal system is not possible, designating at least one recycling or reuse station for material separation is highly advised. It is also recommended that the neighborhood have an organized disposal strategy for yard wastes and hazardous household waste like solvents and batteries. Final design guidelines regard aspects of street design and suggest locating recycling receptacles in mixed-use and nonresidential areas on every block or at least every 800 feet, whichever is shorter (Congress for New Urbanism et al., 2011).

5.3.6.9 Light pollution reduction

The visibility of light pollution through sky-glow at night disrupts wildlife. To reduce light pollution and alleviate the urban environment's overall impact on wildlife, LEED neighborhood design guidelines stress the implementation of motion control sensors in residential areas (Congress for New Urbanism et al., 2011).

5.3.7 Livable Community

This section discusses the vision outcomes of residential housing, civic/public space availability and walkability, community outreach and involvement, neighborhood schools, and recreation.

Table 8 Livable Community

Vision Outcome	Design Guideline	References
Civic/ Public Space	Locate and/or design the project such that a civic or passive-use space, such as a square, park, or plaza, at least 1/6 acre in area lies within a 1/4-mile walk distance of 90% of dwelling units and nonresidential building entrances. Spaces less than 1 acre must have a proportion no narrower than 1 unit of width to 4 units of length. For projects larger than 7 acres, locate and/or design the project such that the median size of civic or passive-use spaces within and/or contiguous to the project is at least 1/2 acre.	LEED-ND pp. 67
Community Outreach and Involvement	Meet with adjacent property owners, residents, business owners, and workers; local planning and community development officials; and any current residents or workers at the project site to solicit and document their input on the proposed project prior to commencing a design. Work directly with community associations and/or the local government to advertise an open community meeting, other than an official public hearing, to generate comments on project design from the beginning. Host an open community meeting, other than an official public hearing, to solicit and document public input on the proposed project at the beginning of project design. Modify the project's conceptual design as a direct result of community input, or if modifications are not made, explain why community input did not generate design modifications. Establish ongoing means for communication between the developer and the community throughout the design and construction phases and, in cases where the developer maintains any control during the post construction phase.	LEED-ND pp. 72

Neighborhood Schools	Include in the project a residential component that constitutes at least 30% of the project's total building square footage, and locate or design the project such that at least 50% of the dwelling units are within a 1/2-mile walk distance of an existing or new elementary or middle school building entrance or within a 1-mile walk distance of an existing or new high school building entrance. For any new school, the school district or equivalent organization must commit in a legally binding warrant that the school will be open by the time of occupancy of 50% of the project dwelling units. Streets within and/or bordering the project boundary that lead from dwelling units to the school site must have a complete network of sidewalks on both sides and either bicycle lanes or traffic control and/or calming measures. If the school is planned as part of the project, it must be designed such that pedestrians and cyclists can easily reach building entrances without crossing bus zones, parking entrances, and student drop-off areas.	LEED-ND pp. 76
Recreation	Locate and/or design the project so that a publicly accessible outdoor recreation facility at least 1 acre in area, or a publicly accessible indoor recreational facility of at least 25,000 square feet, lies within a 1/2-mile walk distance of 90% of new and existing dwelling units and nonresidential building entrances. Outdoor recreation facilities must consist of physical improvements and may include "tot lots," swimming pools, and sports fields.	LEED-ND pp. 68

5.3.7.1 Civic/public space

Addressing the social aspect of sustainability has been outlined as an important accomplishment (Goody Clancy 2011a; Goody Clancy et al. 2011c). Neighborhood design can incorporate parks, squares, and inviting sidewalk and space. The presence of civic areas can increase the likelihood of random public interaction and foster community ties. These areas also become culturally established meeting places for recreation and other healthy social diversions. Widely-cited sources such as *Reclaiming the City* and *The Death and Life of Great American Cities* emphasize the importance of promoting a sense of community within a neighborhood. (Coupland, 1997; Jacobs, 1961).

5.3.7.1.1 Walkability

Civic space substantiates in areas where users are allowed to observe and interact with each other within reasonable proximity. Civic spaces are more likely to remain lively when they are within walking distance. LEED neighborhood design guidelines require civic spaces to have ¼ mile walking distance to 90% of dwelling units (Congress for New Urbanism et al., 2011).

5.3.7.1.2 Availability

According to LEED neighborhood design guidelines, squares, parks, and plazas are the major classifications of civic and passive-use spaces. These spaces are recommended to be at least one-sixth an acre in area. Spaces less than an acre should have a perimeter ratio of 1:4 (Congress for New Urbanism et al., 2011).

5.3.7.2 Community outreach and involvement

The aforementioned community ties that make a neighborhood socially sustainable are a mechanism for civic involvement. When citizens are socially engaged with each other, it becomes less difficult to begin the process of evaluating the needs and concerns of a community. Outreach is a key facet to social sustainability. As the IBC develops in stages, social sustainability can only be maintained if the IBBB community is routinely involved in decision making processes (Silberstein, J. & Maser, C. 2000).

The IBBB district has successfully begun this process. Public meetings have been held about the district's future with attendees ranging from Inner Belt property owners to Brickbottom residents (Goody Clancy 2011a; Goody Clancy et al. 2011c). Community outreach and involvement in the planning process should begin with every stakeholder, including, "property owners, residents, business owners, and workers; local planning and community development officials," as well as special interest groups (Congress for New Urbanism et al., 2011).

The vision outcome of community involvement is to facilitate public meetings that provide individuals a forum to voice input about conceptual designs. It is the responsibility of planning officials to respond to the feedback provided at these meetings. In response to feedback, the conceptual design should either be modified to reflect the opinions of the community or, in the case that modifications are not made, the community should be informed as to why particular modifications were not made to the conceptual design despite their input (Congress for New Urbanism et al., 2011). Effective execution of this process aims to facilitate a planning process that is both equitable and transparent.

5.3.7.3 Neighborhood schools

Early assessment of the community's vision for Planning for the IBBB envisions the area becoming a "great place to … learn". (Goody Clancy et al., 2011c). Should a school become a necessity to the Inner Belt, LEED neighborhood design guidelines recommend that schools be located within ½ mile to at least half of the neighborhood's dwellings. The area surrounding the school should also implement traffic calming measures for automobiles to make it easier and safer to encourage walking and bicycling to school (Congress for New Urbanism et al., 2011).

5.3.7.4 Safety

Safety is central to any community. In addition to compliance with appropriate regulations, this vision outcome is supported by increasing the number of people both on the streets and overlooking the streets through windows. Buildings adjacent to streets with street-facing windows and doors are key for the latter, while the former can be encouraged via high density and transit in proximity to major pedestrian routes (Durham-Jones & Williamson, 2009).

5.3.7.5 Recreation

A community that embraces opportunities for public respite will contribute towards creating social capital. The IBBB Plan envisions the area as a "great place to ...play" (Goody Clancy et al., 2011c). Open space such as parks can provide public access to green spaces will attract community residents towards the IBC area (Zimbabwe, 2010; Goody Clancy 2011a). Employees of local businesses will be able to utilize public recreation areas as meeting places and a location to spend time during breaks. In order to achieve this outcome, a certain percentage of land will be designated for recreation in a design guideline.

6.0 Somerville Context: Analysis of Local Approaches

The project team analyzed local approaches related to development in Somerville in terms of their agreement with the design guidelines and ability to fulfill the vision outcomes. The first such local approach examined in Section 6.1 is the overall Inner Belt/Brickbottom Plan (IBBB Plan) designed by Goody Clancy for the City of Somerville. Next, in Section 6.2, Goody Clancy's IBBB Plan layout of a future Inner Belt Core (IBC) is analyzed. The third local approach examined is an example for mixed-use development in Somerville in the form of zoning and land use controls developed for the Assembly Square Mixed Use Analysis District. These approaches were analyzed as discussed in Chapter 3: Urban Planning Methodology and the discussion of the analysis in this chapter is divided by the two local approaches and relevant key principles.

6.1 Inner Belt/Brickbottom Plan Analysis

Goody Clancy has developed an Inner Belt/Brickbottom Plan for the City of Somerville, including a basic layout of redevelopment that aims to fulfill the City's values. Table 9, below, provides insight as to how the IBBB Plan resonates with many of the ideas touched upon in our key principles. The development of the project team's key principles and analysis of the IBBB Plan were not a linear process; rather, both project elements informed the other and were developed simultaneously. Various aspects of the IBBB Plan from which a foundation for the key principles can be developed are the broad vision (Goody Clancy et al., 2011b), opportunities key to the vision (Goody Clancy et al., 2011a), means for achieving the plan's goals (Goody Clancy et al., 2011a), and long term goals (Goody Clancy et al., 2011c). Altogether the IBBB Plan is in harmony with the key principles, although some are emphasized more than others.

Table 9 IBBB Plan Foundation for Key Principles

Key Principle	Broad Vision	Key Opportunities	Goal Achievement	Long Term Goals
Mixed-Use Development	"Create a new mixed-use Somerville"	"Leveraging life sciences and institutional convergence with university facilities near the study area"	"Mixed-use development including new housing and retail options as well as office and research"	"Create a … community that … includes a mix of uses"
Economic Development	"A place that attracts skilled and educated workers, and therefore significant investment" "An amenity and source of economic opportunity for Somerville and the region"	"Expanding Somerville's job base by leveraging its own high-quality workforce and connections to high-quality regional workforce" "Expanding Somerville's commercial tax revenues through expanded business activity"	N/A	"Create a … community that … that creates jobs, fiscal benefits, and opportunities for Somerville residents"
Connectivity, Walkability, and Modal Variety	N/A	N/A	"Enhanced transit access" "Safe, inviting pedestrian connections within and beyond the study area" "More convenient vehicular connections" "Extension of the Somerville Community Path"	"Create a "TOC"…a transit-oriented community that is walkable"

Key Principle	Broad Vision	Key Opportunities	Goal Achievement	Long Term Goals
Identity and Sense of Place	"Create a new… Somerville neighborhood of choice"	N/A	"Distinguished streets, parks and architecture that lend a strong new identity to this area and all of Somerville"	N/A
Environmental Sustainability	N/A	N/A	N/A	"Create a … community that … embodies Somerville's commitment to sustainability"
Livable Community	N/A	"Creating recreation opportunities serving all of Somerville"	"Creation of new public park space"	"Create a … community that is … a great place to work, live, shop, play, learn" "Create a … community that … enhances quality of life"

6.2 Goody Clancy Layout Analysis

To correspond with the Inner Belt/Brickbottom Plan, Goody Clancy produced a preliminary redevelopment layout. This section analyzes this layout, and then discusses and ranks the basic elements of Goody Clancy's street layout according to importance and feasibility for the project team's design. Analysis of the Goody Clancy Layout focuses on the key principles of mixed-use development; economic development; connectivity, walkability, and modal variety; and identity and sense of place. The project team will apply some of Goody Clancy's street grid and connectivity ideas when developing infrastructure improvements, although not all of them will be incorporated in our design.

Figure 24, below, is a reproduction of Goody Clancy's layout for potential redevelopment in IBC. It highlights issues and opportunities associated with redevelopment in IBC with regard to transportation-oriented infrastructure. It delineates areas of improvement for priority walkable connections, key commercial and/or residential corridors, priority transit- and pedestrian-oriented development, key "gateways", and high priority "green corridor[s]" (Goody Clancy et al., 2011b). Comments inserted into the figure specifically discuss improvements such as adding walkable street connections to form a grid, new street access across rail corridors, and improving walking connections.

One key omission that will be discussed further is that of the Community Path. The Community Path is planned to run alongside the Green Line Extension through the Washington St. Station, and includes planned connections into IBC (MassDOT et al., 2011a). Taking the Community Path into account greatly improves access to IBC and changes the dynamics of the area since it permits pedestrian and bicycle traffic from the station directly into the Inner Belt Core, circumventing the indirect path of the area's street grid into the Inner Belt Core.

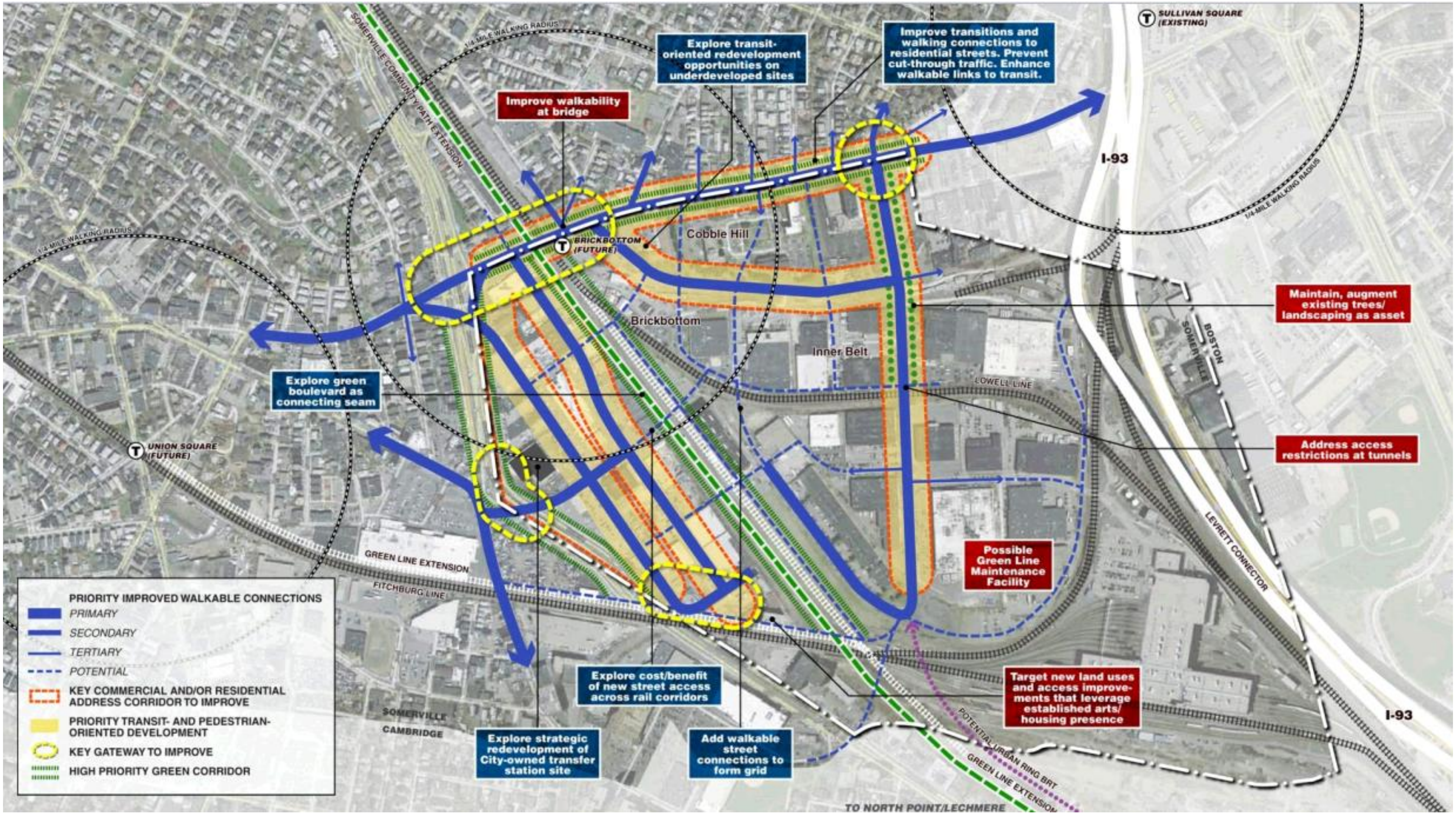

Figure 24 Goody Clancy layout map of issues and opportunities

6.2.1 Mixed-use development & Economic development

Discussion of the key principles of mixed-use development and economic development occurs together since Goody Clancy's layout does not specifically affirm or conflict with these principles. Generally, this layout is limited in scope and does not provide extensive details for a vision of mixed-use or economic development. It emphasizes walkability, which is key to economic success of mixed-use development. It also specifies key commercial and/or residential corridors to improve, such as the central stretch of Inner Belt Road through the Commuter Rail Underpass before the leftward bend, and offers suggestions for major areas of development. It is important to note that since the layout does not take the Community Path through Washington St. Station into IBC into consideration, it does not incorporate the benefits of this additional access point. The second half of Inner Belt Rd could become a focal point of development if the Community Path is taken into consideration, with benefits extending into the surrounding area.

6.2.2 Connectivity, walkability, and modal variety

The Key Principle of connectivity, walkability, and modal variety is the focus of the Goody Clancy layout. An analysis of the layout according to the vision outcomes and Design Guidelines revealed that while the basics of the layout matched the project team's goals qualitatively, they did not necessarily correspond quantitatively. Table 10 compares different Design Guidelines for the vision outcomes relating to connectivity, walkability, and modal variety that are addressed in the Goody Clancy layout.

Table 10 Analysis of Goody Clancy Layout

Vision Outcome	Design Guideline	Goody Clancy Metric	Agreement
External connectivity	7-8	6	No
Intersection frequency	13	5	No
Internal connectivity	Straight	Curved	No
Bicycle path network	Yes	No	No

With regard to external connectivity, the Goody Clancy layout does not meet LEED-ND standards, but these standards may be impractical for Inner Belt Core. There should ideally be 7-8 connections between IBC and the surrounding area, assuming an IBC perimeter of 5000-6000 feet. LEED-ND standards call for connections across the project boundary at least every 600 ft on average, as well as at least every 800 ft in each case (LEED-ND specifies that non-motorized ROW can be 20% of the total at most) (Congress for New Urbanism et al., 2011). The Goody Clancy vision has only 6 connections, and thus does not meet the LEED-ND standard. However, Inner Belt Core faces unique connectivity problems due to the difficulty of crossing the rail lines. Additionally, the cost of 80% motorized ROW connections would likely be prohibitively high.

One major critique of external connectivity in the Goody Clancy layout is that the Community Path, again, is not displayed. The Community Path is a key external connection formally planned as part of the Green Line Extension; it could directly connect the IBC to the Washington St. Station, putting much of the IBC within ½ mile of transit. Not only does the exclusion of the Community Path from the Goody Clancy layout impact its external connectivity, but also causes it to not satisfy the LEED-ND design guideline focused solely on the availability of a bicycle path network. Feasibility of Community Path connections was discussed at a Community Path Design Workshop of the Green Line Extension Project; the workshop presenters spoke of connecting to Brickbottom as challenging, but discussed solutions being examined (personal communication, Community Path Design Workshop, September 9th, 2011).

The Goody Clancy layout's potential connections to Brickbottom are very important to external connectivity, though they are by no means guaranteed or easily feasible. Brickbottom is an important cultural center of Somerville known for its artist population (Goody Clancy et al., 2011c). Furthermore, the area beyond Brickbottom is desirable to connect to as the squares there are cultural centers and key destinations, as noted by participants at an IBBB focus group meeting (Goody Clancy et al., 2011d).

Potential connections from IBC to North of the Tubes are less important and of uncertain feasibility. Feasibility of these connections was not discussed at the October 5th IBBB Plan meeting, and it appears to be challenging to cross the commuter rail. North of the Tubes is not currently a cultural area, though the market analysis shows further development happening in conjunction with the Green Line Extension. A general connection to the area already exists; Inner Belt Rd. A community path connection to the Washington St/ Brickbottom Station could also provide a connection to the North.

The intersection frequency Design Guidelines were not met by the Good Clancy layout. According to LEED Neighborhood Development standards, there should be about 13 intersections in IBC, assuming an IBC area of 1/7 mi^2. LEED-ND standards call for 90 intersections/ mi^2 (Congress for New Urbanism et al., 2011). However, Goody Clancy's layout currently only has 5 intersections within its proposed street grid. See the blue lines in Figure 24, above, which compose its proposed street grid.

The project team's street grid will, like Goody Clancy's avoid dividing buildings (and properties) where possible, but will prioritize an effective street grid. Saving buildings with the intent to retrofit and repurpose them is an option. However, the existing buildings in the area may not necessarily support uses that are consistent with the vision. The current layout of buildings in the IBC seems to prevent logical street grid connections, and the street grid proposed in the Goody Clancy vision does conclude with splitting some existing buildings.

6.2.3 Identity and sense of place

By preserving the existing street layout and buildings where possible, the Goody Clancy layout offers to some degree the ability to keep at least this aspect of the area's current identity. However, since the proposed future transit-oriented, mixed-use development is radically different than the current light industrial development, much of the Inner Belt Core will change. Layout contributes only partially to identity and sense of place, so this Key Principle cannot be fully evaluated here.

6.3 Assembly Square Mixed-Use District Analysis

Somerville has developed a 2004 document compiling mixed-use development land use controls and guidelines for a future mixed-use development site in neighboring Assembly Square. This Somerville district is the most recent large-scale, mixed-use development in Somerville and establishes zoning precedents and district design guidelines of direct relevance for redevelopment in the Inner Belt Core (IBC). This section analyzes Assembly Square and considers major aspects applicable to the project team's design.

Information from this new zoning precedent will be applied judiciously to our project, as the nature of the Inner Belt area is different than that of Assembly Square. When asked about the applicability of precedents set by the Assembly Square Mixed Use Development District (ASMUD), Somerville Chamber of Commerce CEO Stephen Mackey listed some of the major differences to consider. Such differences include the differing capacities of the Orange Line serving ASMUD and the Green Line serving IBC, attractive waterfront property in ASMUD that is not a factor in IBC, and the larger lot sizes present in Assembly Square (personal communication, Stephen Mackey, December 9, 2011). These differences mean that the two areas need different infrastructure improvements to facilitate redevelopment. These differences likewise impact developers' views of the two sites and result in different redevelopment transition planning needs. Nevertheless, land use controls applied in Assembly Square are still pertinent to the Inner Belt Core.

6.3.1 Mixed-use development & Economic development

Assembly Square Mixed-use District document outlines two specific goals concerning mixed-use development and economic development. These goals are to:

- Facilitate development of a mix of uses including residential, office, research and development, retail, hotels, cinemas, performing arts and institutional uses
- Increase real estate investment and maximize development (City of Somerville, MA, 2004)

Mixed-use development contrasts contemporary Euclidean zoning, which relies on strict definitions for land use and functions by partitioning land uses into separate clusters. Mixed-use development, as the name implies, works to oppose the separation of land uses that transpires in Euclidean zoning. Since Somerville land use is regulated by Euclidean zoning categories, Assembly Square Mixed-Use District was established as a separate land use zone in order to adhere to municipal planning conventions.

It is often in the best interest of developers and city planners to orchestrate a coordinated development approach that results in a financially sustainable neighborhood. A mixed-use zone could theoretically accumulate a range of uncoordinated structures and land uses that are not economically sustainable. To prevent this, the Assembly Square Mixed-use District document specifies a special regulatory process that governs the mixed-use development process in Somerville's Assembly Square mixed-use zone (City of Somerville, MA, 2004). This regulatory process is designed to ensure that Assembly Square retains a functional zoning pattern during development.

According to the Assembly Square Mixed-use district document, developments and contracting projects in Assembly Square will be categorized either through a Special Permit Granting Authority process or a Planned Use Development process. The Special Permit Granting Authority process manages affordable housing development, transit-oriented and high density development, and developments prompting the need for many retail tenants. The Planned Use Development process manages other types of development projects that express interest in Assembly Square (City of Somerville, MA, 2004). Every potential development must be approved by Somerville's Planning Board, serves as a Special Granting Authority. This authority has the power to approve, approve with conditions, or deny developments in the application process and administer final site approval (City of Somerville, MA, 2004).

It is evident that the Assembly Square Mixed-Use Development District utilizes a substantial amount of municipal governance. This public oversight and application process for development serves to compose an organized and functioning mixed-use neighborhood. The City of Somerville should likely assume a similar development approach in the Inner Belt and Brickbottom area.

6.3.2 Connectivity, walkability, and modal variety

Assembly Square Mixed-use District document outlines three specific goals concerning connectivity, walkability, and modal variety. These goals are to:

- Promote accessibility to and within the district by improving existing and creating new roadways, pedestrian walkways and bicycle paths
- Improve utilities and infrastructure
- Encourage transit-oriented development (City of Somerville, MA, 2004)

Assembly Square faces some of the same challenges and development potential as the IBC. Assembly Square is currently in the process of redeveloping from a former use as a light-industrial area. Before redevelopment work began, the area lacked a comfortable degree of walkability. Substantial roadway connections to surrounding neighborhoods and arterial roads were also absent. In the Assembly Square Mixed-use District planning document, a significant amount of attention has been given to make assembly square more accessible to a variety of transportation modes. An MBTA Orange Line station will be connected to provide non-vehicle access to the area. Sidewalks will have substantial width standards of at least 8 feet. There are also open space bonuses allotted to developers who incorporate open public space into their designs.

Somerville has established municipal development precedents in Assembly Square to improve access near future rail-transit, enhance walkability, and establish better roadway connections to surrounding neighborhoods. Auspiciously, many development ideas published in 2004 for Assembly Square resonate with the latest LEED Neighborhood Design Standards (published in 2009) and are applicable to the needs of the Inner Belt Core.

6.3.3 Other Observations

In addition to Somerville's goals for creating a successful mixed-use, transit-oriented development in Assembly Square, The Assembly Square Mixed-use District document from 2004 has several additional development goals similar to the key principles developed in Chapter 5 of this report. Specifically, The Assembly Square Mixed-use District document alludes to the key principles of identity and sense of place;

- Improve the Mystic River waterfront and create new public open space

diversity and mixed-incomes;

- Create new jobs at a variety of income and skill levels
- Increase the supply of affordable housing units within the City of Somerville

environmental sustainability;

- Clean environmentally contaminated sites to a level suitable for a mix of uses including residential and livable community;

- Replace vacant or underutilized land, low-density development, and incompatible uses with high-density mixed-use development (City of Somerville, MA, 2004).

As presented above, Assembly Square's development goals are directly correlated with Chapter 5's key principles. Somerville's current approaches to mixed-use development align with state-of-the art development principles researched and presented in earlier chapters of this report. To a notable degree, this substantiates the feasibility of incorporating Chapter 5's key principles as a local approach for strategic development in the IBC.

7.0 Design and Implementation of Best Practices

This chapter presents final designs for the Inner Belt Core. It illustrates solutions for critical connectivity infrastructure enhancements, such as the Community Path extension route, pedestrian access to Brickbottom, roadway access to Brickbottom and to North Point, and street design recommendations for Inner Belt Rd. These connectivity enhancements are summarized in Figure 25 below. Subsequently, Chapter 8 presents a potential engineering solution for enhancing the IBC's connectivity near a commuter rail underpass known as "the Tubes."

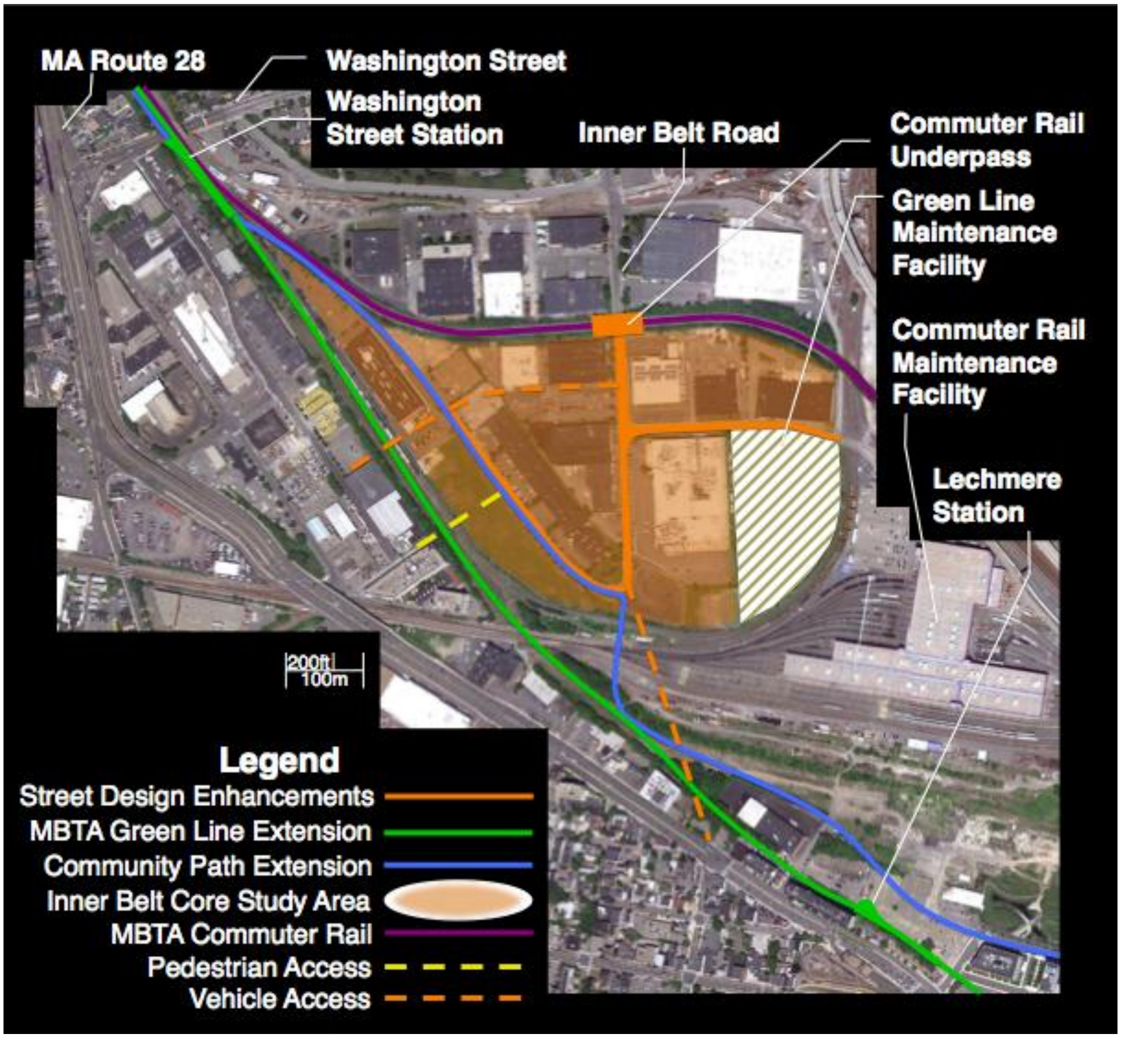

Figure 25 Overview of Suggested Connectivity Enhancements

7.1 Community Path Extension Route

The Community Path extension lies at the heart of redevelopment in the IBBB, and offers particular advantage to the Inner Belt Core. As aforementioned in Section 2.5.1, the Somerville Community Path is a right-of-way for pedestrian and bicycle traffic in northwestern Somerville. It has regional connections to nearby city centers and currently terminates at Cedar St., relatively close to Somerville City Hall, Somerville High School, and Somerville Public Library. Extending this right-of-way eastward towards Somerville's Union Square and Inner

Belt/Brickbottom is included as an aspect of the Green Line Extension project. Collaboration between community groups and engineering firms involved with the Green Line Extension affirmed the Community Path as playing a significant role in Inner Belt/Brickbottom's future. Through connecting the Community Path to the Inner Belt Core, the area becomes connected to these neighboring amenities.

Despite the certainty surrounding extension of the Community Path, final decisions are yet to be made about the path's exact route through the Inner Belt/Brickbottom neighborhood. As of February 2012 an entrance to the IBC via the Washington Street Station through the northwest corner of the IBC is being planned by Green Line Extension team (STEP, 2012). See Figure 26, below. According to these plans, the station will connect to both the Inner Belt Core (upwards on map) and to Brickbottom (to the left on map) via tunnels. Thus the station itself will serve as a connection between these two neighborhoods. Further designs continuing the route beyond this entrance have not yet been proposed.

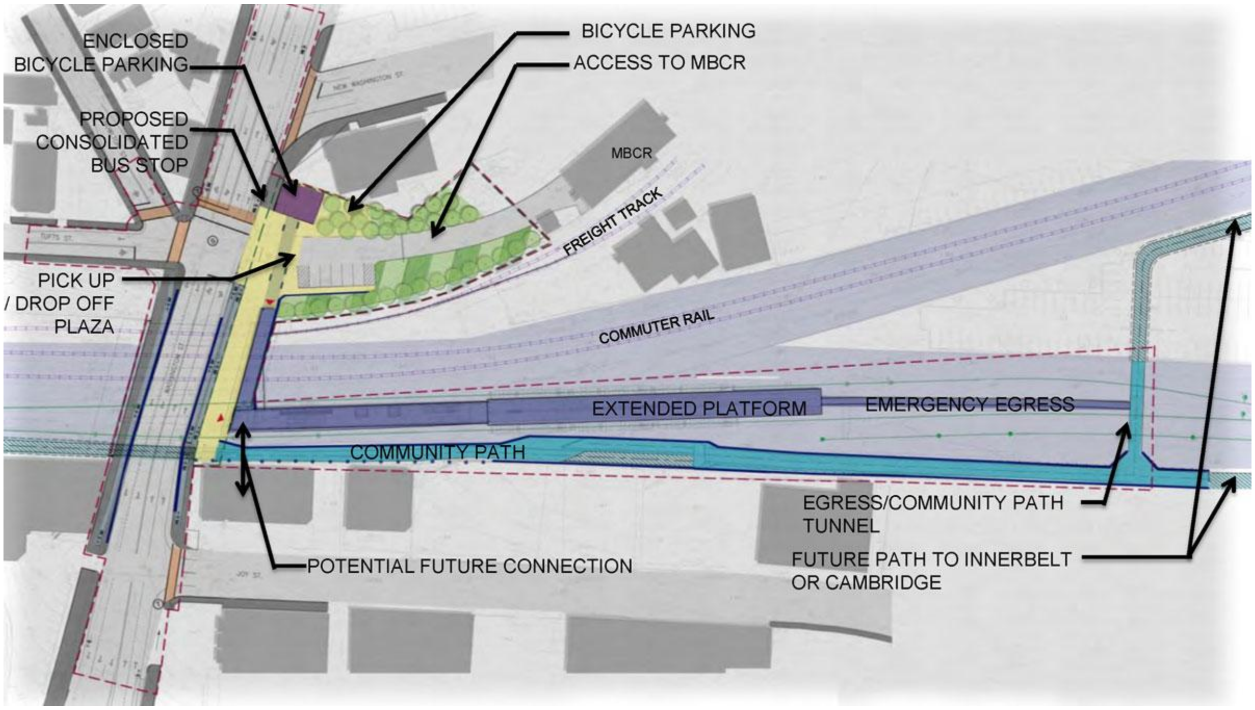

Figure 26 Community Path Entrance to IBC from Washington Street Station

Figure 27 highlights a proposed route for the Community Path extension. This specific route could play an important role in improving non-motorized connectivity in the IBC. The dashed red line indicates a potential journey path from the southern IBC to the future Washington Street Station without the Community Path. Without the proposed extension route, the journey from the southern IBC to Washington Street Station is relatively indirect and time-consuming. The blue and yellow dashed journey path indicates a safer, quicker, and overall more convenient route from the southern IBC to Washington Street station for pedestrians and bicyclists.

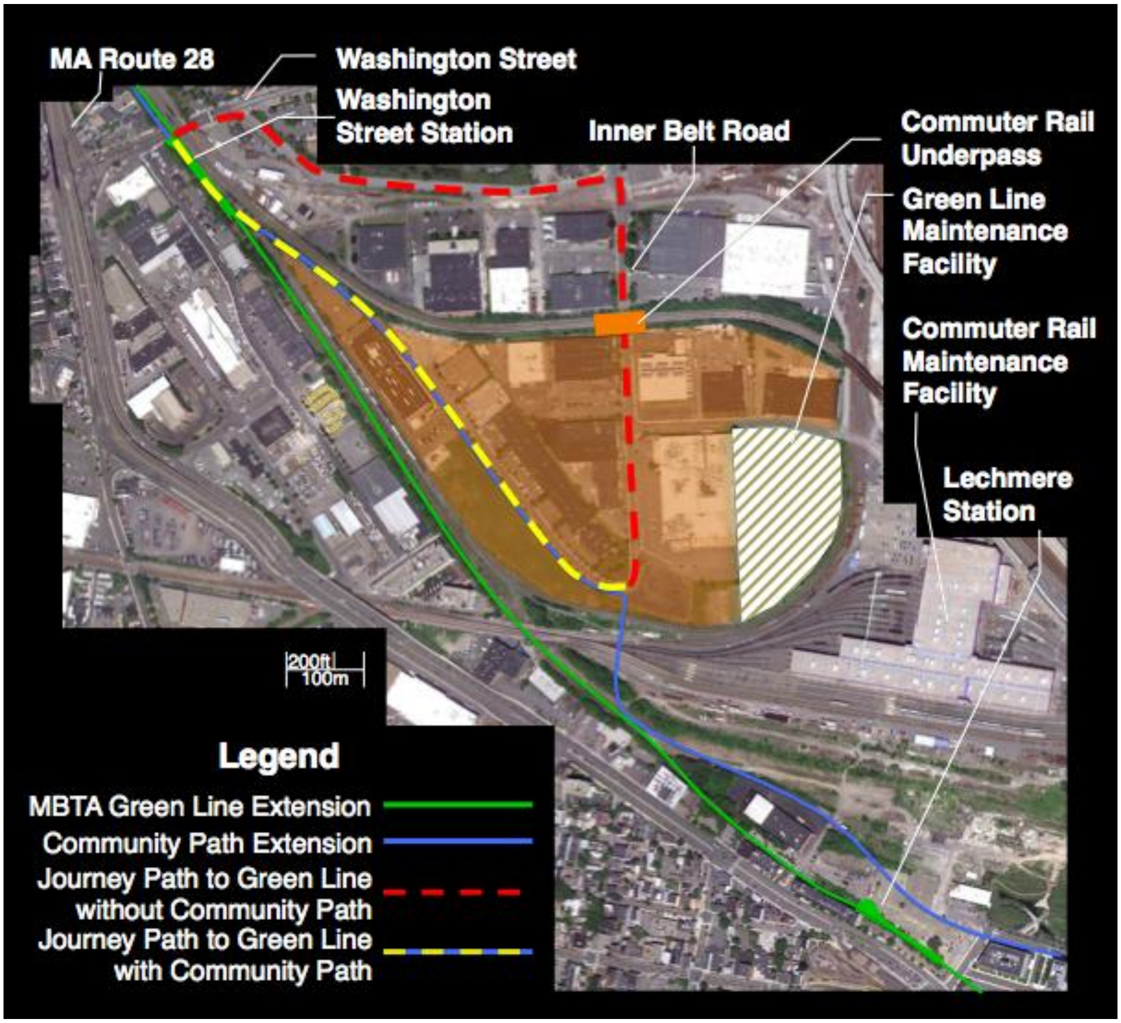

Figure 27 Non-motorized Travel to Washington Street Station Enhanced by Community Path Extension Route

7.2 Potential Pedestrian access to Brickbottom

Another component of the suggested connectivity enhancements would strictly emphasize non-motorized access between Brickbottom and the IBC. This would be achieved by constructing a pedestrian tunnel or bridge circumventing the future Green Line Extension railway. The route of this pedestrian connection is illustrated in Figure 28.

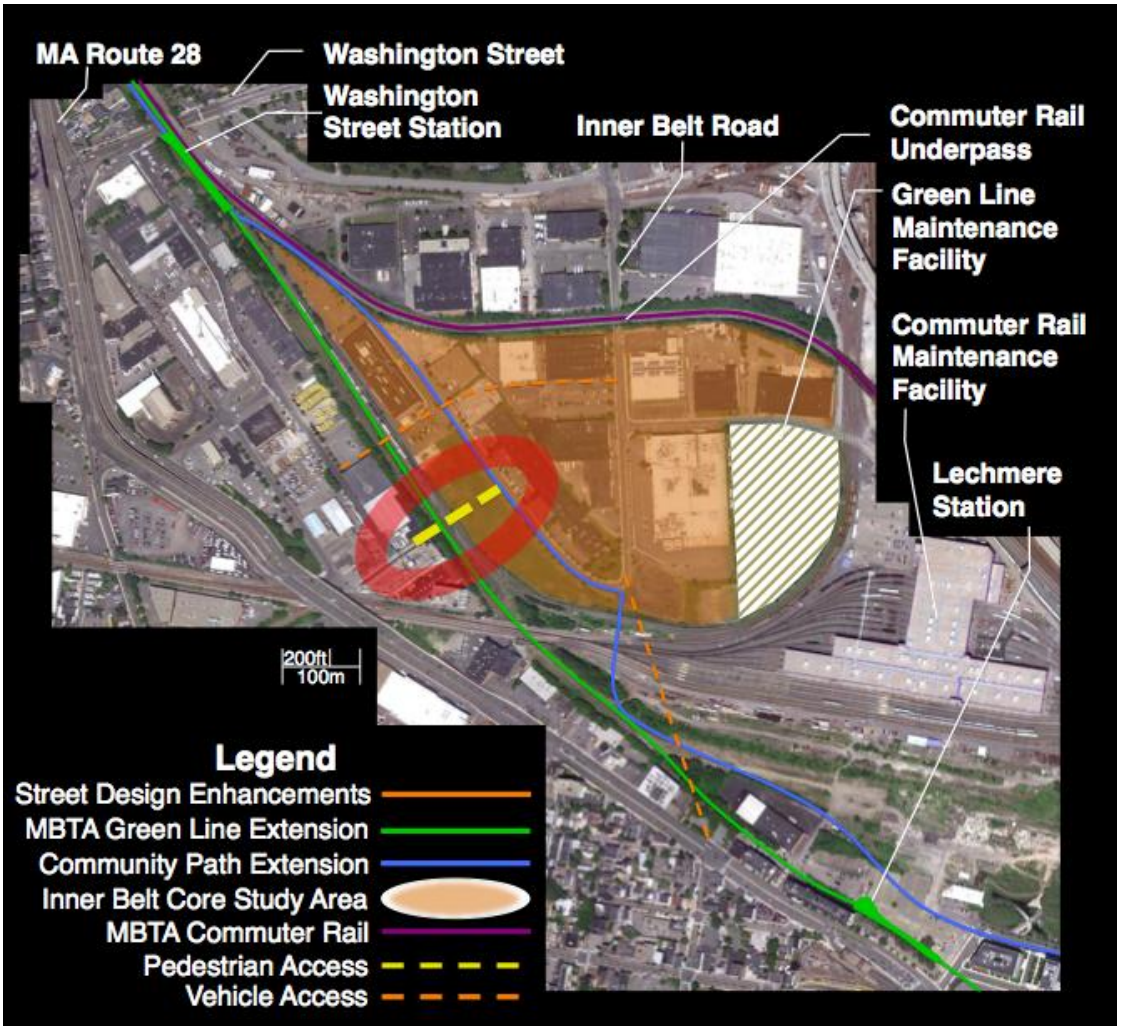

Figure 28 Suggested Pedestrian Connection

By serving local pedestrian traffic, this connection could bolster a sense of community between Brickbottom and the IBC. Brickbottom currently maintains a notable residential population at the Brickbottom Lofts property on 1 Fitchburg St. Residents and visitors would be able to travel between the two neighborhoods as development in the area progresses, potentially linking the IBC's identity with Brickbottom's developing residential identity.

7.3 Potential Multimodal access to Brickbottom and North Point

The IBC relies on one roadway for connection to surrounding neighborhoods, exacerbating the IBC's overall isolation. Two roadway connectors are proposed connectivity enhancements. A Brickbottom roadway connector would establish a westward cross street between Inner Belt Rd. into the Brickbottom neighborhood. Additionally, a rail yard flyover bridge would connect the IBC to Cambridge's nearby North Point development area and MA-28. Figure 29 illustrates the location of the two proposed connectivity enhancements.

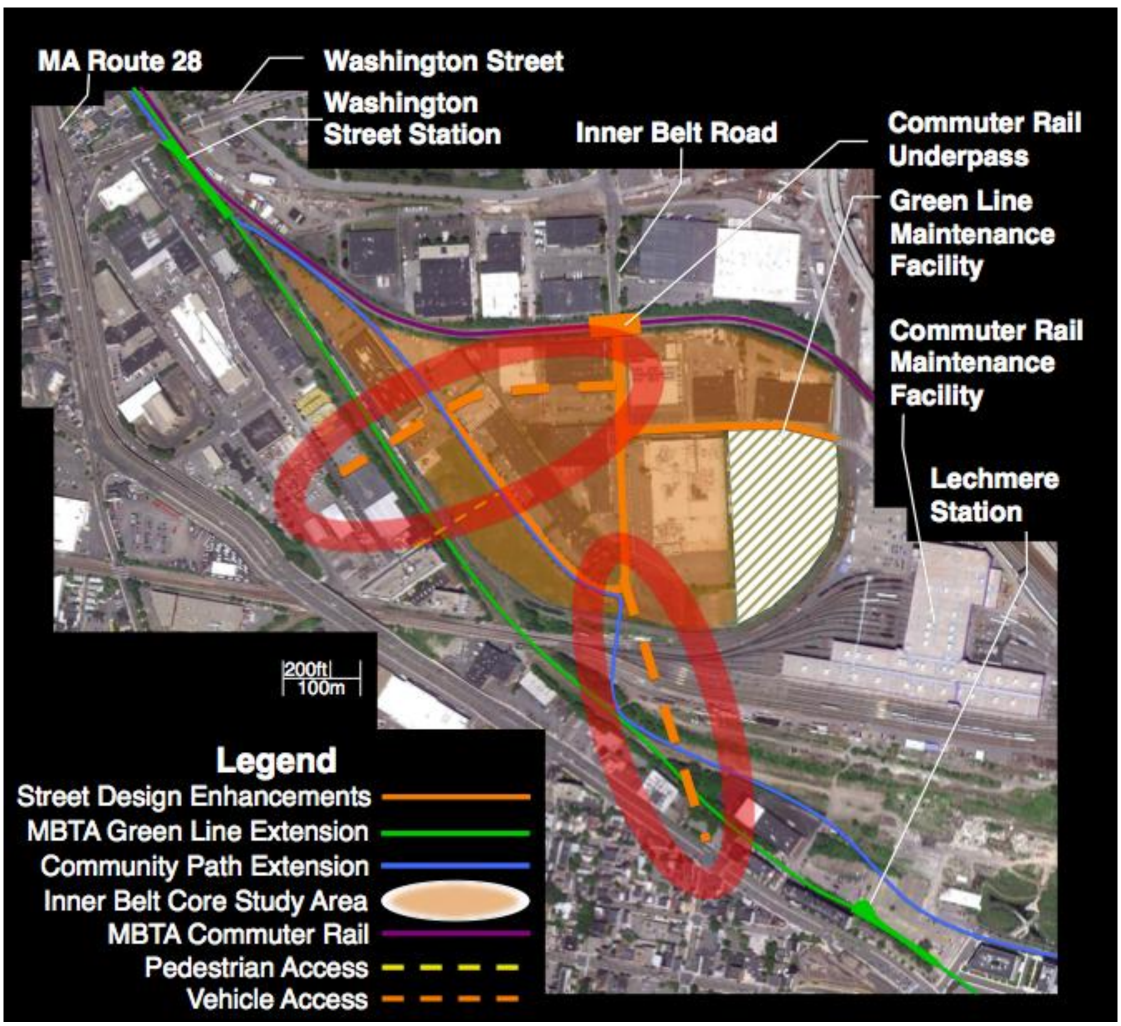

Figure 29 Suggested Roadway Connections

The Brickbottom roadway connector would create another roadway intersection in the IBC, catalyzing the district's desired mixed-use character. It would allow multimodal access between the two neighborhoods. The suggested route encroaches on private property but does not require the demolition of any major structures in the IBC or Brickbottom. The only interrupted land uses would be private parking lots and storage yards.

The recommended rail yard flyover from the IBC to North Point in Cambridge would allow vehicle, bicycle, and pedestrian traffic to permeate between the IBC's Inner Belt Road and a critical segment of MA-28. The purposed flyover's terminus in Cambridge would be within close proximity to Cambridge's new North Point mixed-use development, the MBTA's future Lechmere Station, and further roadway connections to downtown Boston. Due to this area's elevation differences and potential hazards, construction of the rail yard flyover bridge would present significant engineering challenges.

7.4 Inner Belt Rd. Enhancement Profile

The abovementioned sections of this chapter suggest routes to enhance the IBC's overall connectivity for bicyclists, pedestrians, and vehicles. This section describes a potential street profile design for the IBC's main street, Inner Belt Road. This suggested street profile design furthers the theme of improving connectivity. This street profile design is based on road and sidewalk widths originally suggested for mixed-use development in Somerville's Assembly Square. Other elements such as bicycle lane widths, on-street parking, and architectural considerations come from sources mentioned in Chapter 5. Figure 30 below illustrates the final suggested street profile for Inner Belt Road.

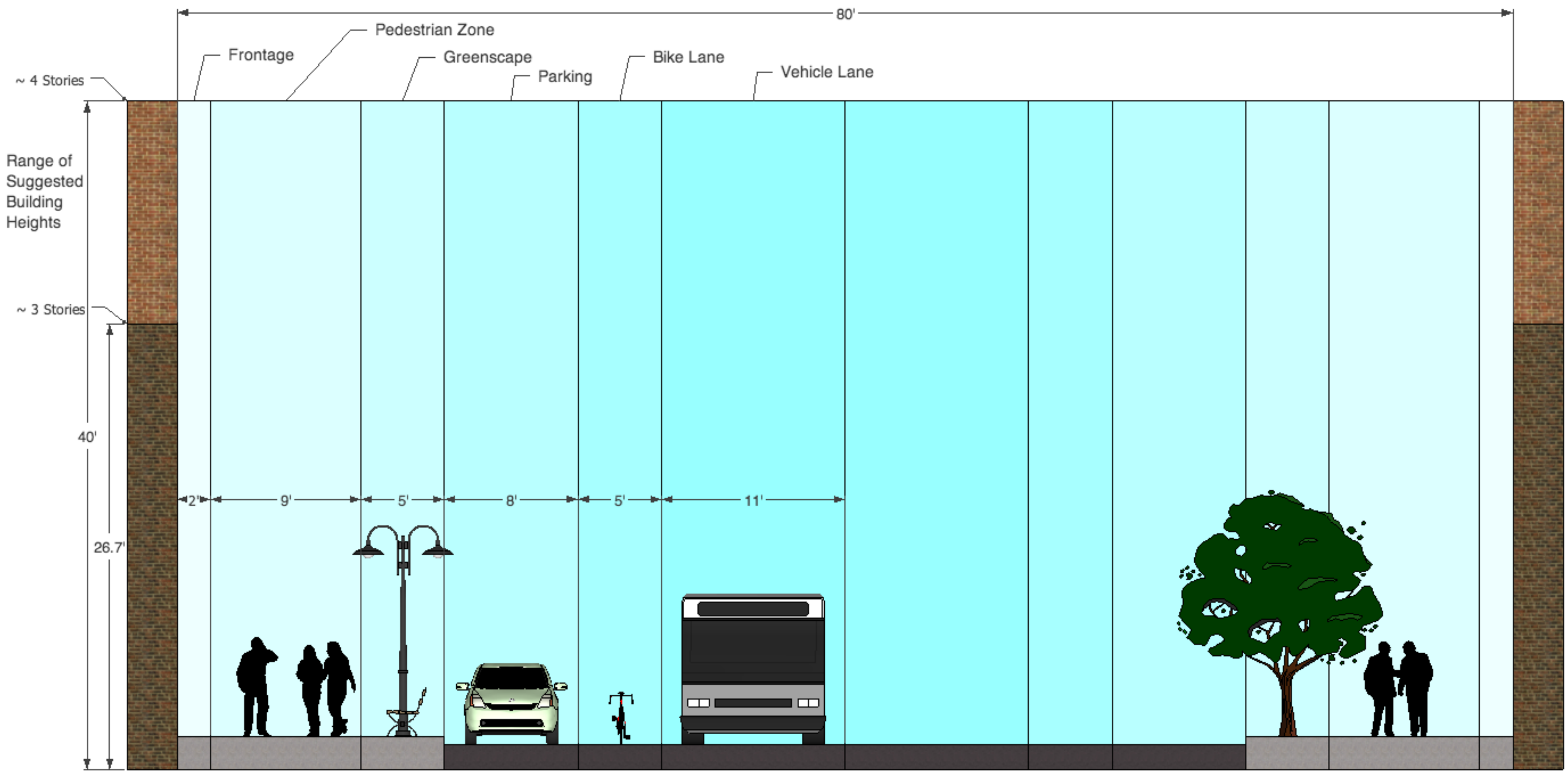

Figure 30 Suggested Inner Belt Road Design Profile

(Pedestrian, lighting, bench, bicycle, vehicle, and tree objects imported from the Google 3D Warehouse)

7.4.1 Street Width to Building Height Ratio

The proposed Inner Belt Road street profile is approximately 80’ wide from building façade to building façade, with . For comparison, the current road is 40-45’ from pavement edge to edge, with building façades set further back beyond landscaped areas. While an 80’ right-of-way would include land currently under the management of private property owners, the project team recommends the redesigned

For this specific total width, building heights between three and four stories are recommended (Oregon TGM, n.d.). Building facades would ideally meet the sidewalk at a 2’ frontage zone to establish a close relationship between building entrances and the street (City of Boston, 2010).

7.4.2 Frontage Zone

The frontage zone of a sidewalk functions as a permeable transition space between building entrances and pedestrian zones (City of Boston, 2010). Although relatively small and often overlooked, this zone can vastly enhance the social atmosphere of a street during storefront business hours. The frontage zone allows pedestrians to linger without interrupting the flow of a sidewalk’s foot traffic. Pedestrians can use this space to look through storefront windows or sit on an outward facing bench. Municipal codes should facilitate desired commercial enterprise uses. For example, businesses could use the frontage zone for daytime advertising, while bistros and cafes could utilize the frontage zone for outdoor seating areas.

7.4.3 Pedestrian Zone

The pedestrian zone is the centerpiece of a sidewalk and the keystone of a walkable neighborhood. This zone operates as a throughway for pedestrian traffic and must be clear of obstructions. Sidewalk furniture, such as advertising, benches, trees, mailboxes, and tables must be kept to the adjacent frontage and greenscape zones. The overall slope and transitions of this zone should be level and even (City of Boston, 2010).

7.4.4 Greenscape/Furnishing

The greenscape zone is the frontage zone's cohort. Beyond being aesthetically pleasing, it operates as a permeable area between the sidewalk and the street. It distinguishes the pedestrian area from bicycle and motor vehicle traffic. This zone can make pedestrians feel separated from the noise and speed of street traffic (City of Boston, 2010). Planted trees in the greenscape zone provide seasonally appropriate shade for pedestrians, buildings, and parked cars. Street furniture such as mailboxes, bike racks, and storefront facing benches are often located in this zone.

7.4.5 Parking

The parking zone allows individuals to access the Inner Belt by private automobile, as it provides a space for short-term parking. Metered short-term parking tends to increase overall turnover for commercial operations in a district. The parking zone is the final safeguard for pedestrians between bicycle and pedestrian traffic. In many cases, sections of the parking zone are designated as loading and unloading zones for cargo delivery.

7.4.6 Bike Lane

A dedicated bicycle zone serves to provide bicyclists with a reliable travel area. In mixed-use developments, bicycling is a highly encouraged form of transportation and favored over private automobile use. The bicycle lane should be unobstructed and clearly marked for safety, making it capable for cyclists to exceed the average speed of pedestrians and potentially rival vehicle speeds. As illustrated, a minimum bike lane width of 5’ should be established when adjacent to on-street parking (City of Boston, 2010).

7.4.7 Vehicle Lane

The vehicle zone is the primary throughway for motor vehicles. The indicated width in this street profile can accommodate transit buses and large vehicles, but can be adjusted depending on the street’s expected percentage of large vehicles. Vehicle lanes in a mixed-use development are relatively narrow to encourage slower vehicle speeds. Additionally, the surrounding human scale architecture often compels vehicle operators to proceed cautiously. The vehicle lane should have a strictly enforced speed limit of no more than 25mph (City of Boston, 2010).

8.0 Commuter Rail Underpass Design

This chapter includes the Commuter Rail underpass design, a construction cost and time estimate, details for site storage, a vehicle traffic detour plan, and a train re-routing plan. Although the structural design considered multiple factors, some loads governed the design. These loads were the dead load, live load, and impact load for both Allowable Stress Design and Load and Resistance Factor Design. The Design is presented below in nine detailed AutoCAD drawings. The construction cost is presented in a table summarizing the key component costs and the time estimate is presented in a flow chart. The site storage, vehicle and train detours are mapped out with details referring to each plan separately. Although one plan is presented in each section, alternative design options are discussed as well. All supporting calculations can be found in Appendix C.

8.1 Railway and Ballast

The design process for the railway and ballast is based on guidelines established by the American Railway Engineering and Maintenance-of-Way Association (AREMA). The dimensions of the bridge are forty-five feet long by thirty-six feet wide. These dimensions are based upon two assumptions. The first assumption is that the MBTA railcars fit within the clearance shown in Figure 31. Therefore a 36 foot width would be required to accommodate two sets of tracks.

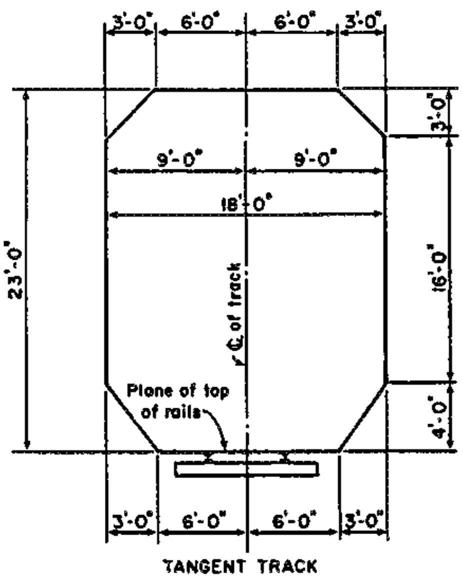

Figure 31 Minimum Clearence for Train Cars (AREMA 2010b)

In addition to the width, the clear span of the bridge has to be sufficient to accommodate two lanes of traffic, two bike lanes, two sidewalks, and leave sufficient clearance for the superstructure to sit on top of the substructure without disrupting the vertical alignment of the rail tracks. The initial superstructure design assumed a value of forty-five feet based on estimated spacing requirements. The final design continued to use this number as the process determined that nineteen inches of the superstructure on each side would extend over the substructure. This left a clear distance of about 41 feet and 10 inches to accommodate the road, bike lanes and sidewalk. The group developed the roadway dimensions detailed in Figure 32 below. These dimensions are based on Boston Complete Streets Standards and Assembly Square Design Guidelines for the Public Realm (City of Boston, 2010; City of Somerville 2002).

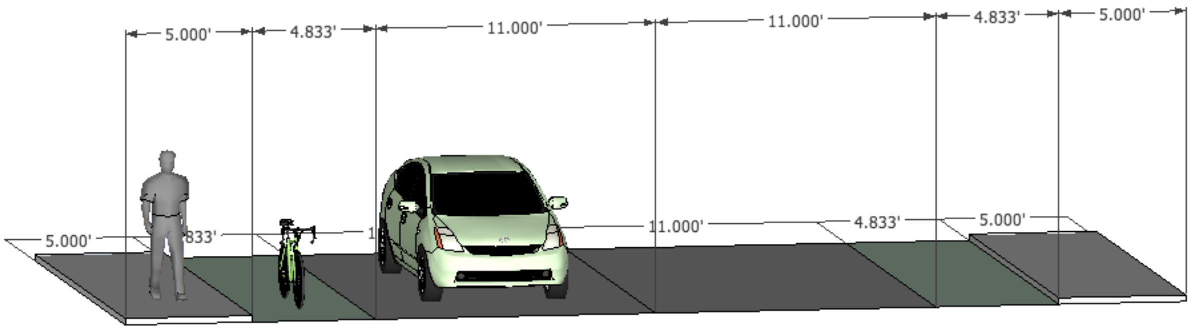

Figure 32 Cross Sectional View of the Street under the Commuter Rail Underpass

(Pedestrian, bicycle, and vehicle objects imported from the Google 3D Warehouse)

The other component of the railway is the ballast, which consists of crushed stone. The train rails rest upon track ties, which in turn rest upon the ballast. For this design, the ballast extends a foot below the track ties, which are already seven inches thick. This depth will allow an appropriate distribution of train loads. Additionally, this will prevent excessive water from building up on the bridge deck by acting as a drainage system. The top view of the bridge can be seen in Figure 33 below. This figure includes section A-A which is shown in Figure 34, under Chapter 8.2.

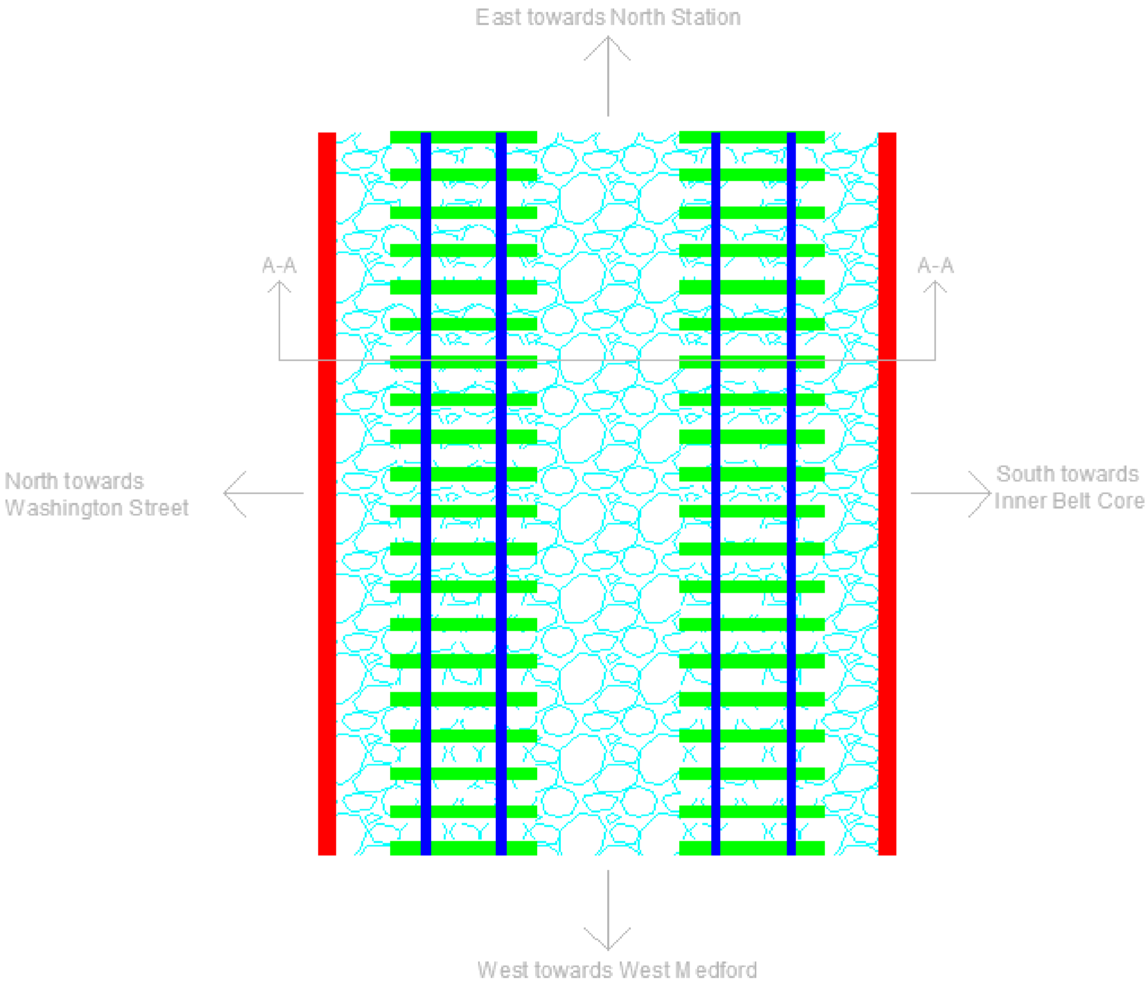

Figure 33 Drawing #1: Top View of the Bridge

8.2 Superstructure

As outlined in the Methodology, the design of the superstructure consisted of designing the structural steel stringers and accompanying lateral bracing, followed by the reinforced concrete deck. Following AREMA strength and serviceability requirements the design of the superstructure included dead, live, impact, wind, longitudinal, snow, and rain loading combinations. The design also considered other loads, such as seismic; however these loads were not included in the design phase either due to minimal force, or through AREMA specifications. A summary of the selected members and materials is presented below in Table 11.

Table 11 Superstructure Components

Superstructure	**Member(s)**
Structural Steel Stringers	W 30x292 (A709, Grade HPS 70W)
Lateral Bracing	W 24x131 (A992, Standard Grade)
Precast Concrete Deck	Standard Construction Concrete (5 ksi)
Deck Reinforcing Steel:	
Top Lateral Support	# 5 Reinforcing Steel Bars
Bottom Lateral Support	# 11 Reinforcing Steel Bars
Lateral Overhang Hooks	# 5 Reinforcing Steel Bars
Top Longitudinal Support	# 5 Reinforcing Steel Bars
Bottom Longitudinal Support	# 11 Reinforcing Steel Bars

Following Table 11, the first phase of the superstructure design was the structural steel stringers and supporting lateral bracing. The stringers are assumed to each carry an equivalent portion of the design loads and are spaced so as to be located under the load path of the train tracks, while supporting the superstructure. The design process included checking the bending stress, axial compression, slenderness ratio, and the deflection due to live and impact loads. Through this analysis the deflection governed the beam design, requiring the selection of eight high performance W 30x292 steel beams. The final design live and impact load deflection is .830 inches and the dead load deflection is .455 inches. Additionally, the stringers are supported by lateral bracing.

The lateral bracing creates a rigid body that disperses the wind loading throughout all of the stringers so the outermost stringers don't take the full effect of the wind loads. Although the wind loads aren't so large as to cause member failure, the bracing provides additional support against rotational or torsional buckling of the stringers. In order to create a uniform distribution of loads through the stringers, the selected bracing sections needed to be about as tall as the flange height of the stringers. This prompted the group to select the lightest section closest to a height of twenty six inches, which was a W 24x131. Following the selection of the member size, the strength of the member was investigated. The investigation included checking the bracing axial compressive force, the slenderness ratio, and the bearing pressure created on the stringers. Generally, members are specifically designed for lateral bracing, however to the best of the team's ability; they selected a beam to complete this job. The group recommends selecting other members that are specifically designed for axial compression and will cost less.

Overall, the analysis determined that five rows consisting of seven members would be sufficient for lateral bracing. Since the stress present in the lateral bracing was not too large (16.4 ksi), the members will be welded to the stringers. If the stress were large, then the bearing pressure on the stringers would be a concern, and the lateral bracing would need to be connected through other means, such as through a medium to distribute the bearing stress over a larger area. In turn, the stringers will be welded to the concrete deck through welding plate, embedded in the pre-cast concrete slab located above it. This is due to the fact that composite action was not considered in the design. The stringers and lateral bracing, along with the rest of the superstructure are shown below in Figure 34.

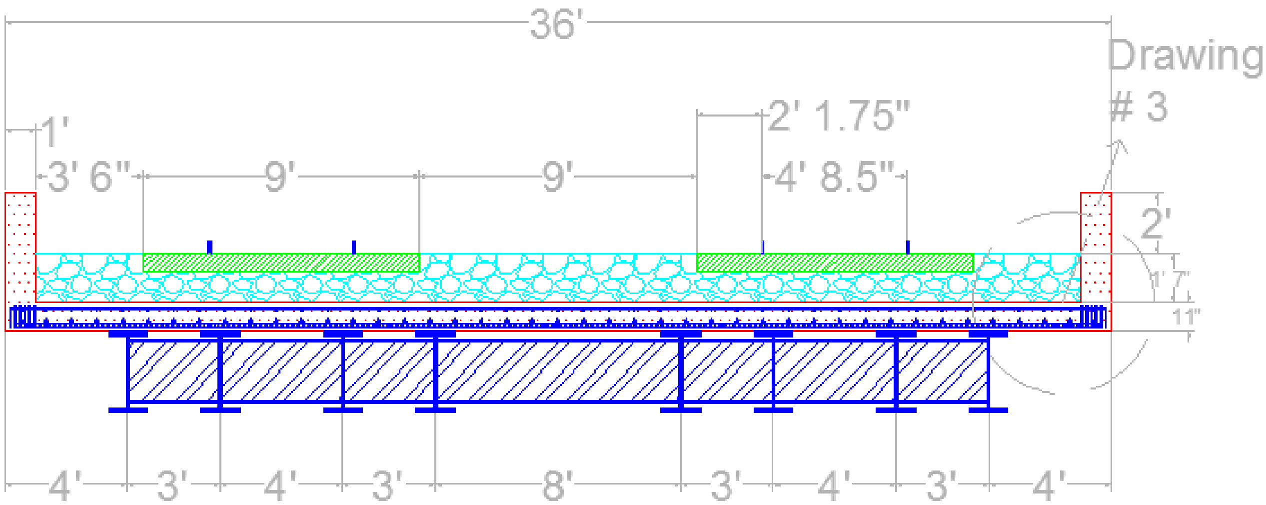

Figure 34 Drawing #2: Section A-A, Lateral View of Superstructure

The design of the reinforced concrete deck was the next phase of the project. Since the deck is supported in the longitudinal direction by the stringers, the lateral reinforcing steel was considered to be the primary design elements. Additionally, based on the stringer design and distributed loads, the largest lateral tensile bending stresses induced in the deck will be on the lower side of the deck, due to positive bending moments. Table 12 below shows this value and summarizes the maximum lateral design moments present in the concrete deck.

Table 12 Lateral Design Moments in the Deck

Location on Deck	Largest Positive Design Moments (K*ft)	Largest Negative Design Moments (K*ft)
Exterior Span (Where no Lateral Bracing is located)	0	14.4
Interior Spans (Where Lateral Bracing is Located)	73.1	14.4

Designing the reinforcing members for this section of the deck included investigating the stress-strain relationship between the concrete deck and the steel. Through initial calculations and assumptions, the group selected 60 ksi reinforcing steel and 5 ksi concrete. These calculations also proved that the initial deck assumption of nine inches was not sufficient and that an eleven-inch thick deck was preferred. With these corrections, the analyses determined that #11 bars spaced on center at eight inches would provide the needed resistance for the deck. The process for the top reinforcing steel was the same as the design of the bottom reinforcing, with the exception of a smaller design moment. This produced a result that recommended #5 bars, which will also be spaced eight inches on center. The other design consideration for lateral bracing was insuring there was sufficient spacing above and below the reinforcement to provide the steel with an effective cover. This spacing can be seen in Figure 35 below. The figure also details the design of the overhang and longitudinal reinforcement spacing, which will be discussed next.

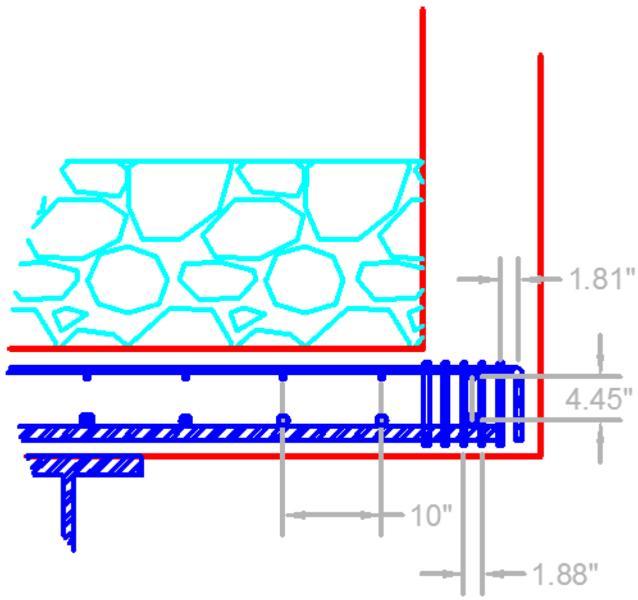

Figure 35 Drawing #3: Reinforcing Detail from Section A-A

With the initial lateral reinforcement chosen, the succeeding step was to address the spacing and overhang. The bottom lateral spacing required a two-inch cover due to its exposure to air, where the top longitudinal reinforcing required an inch and a half cover against the ballast. The overhang design needed to address excessive shearing forces that could develop due to the wall above it. The overhang consists of #5 bars rapped around two rows of lateral reinforcement (four bars altogether) and is tied off creating a U shape. This can be shown below in Figure 36 and Figure 37.

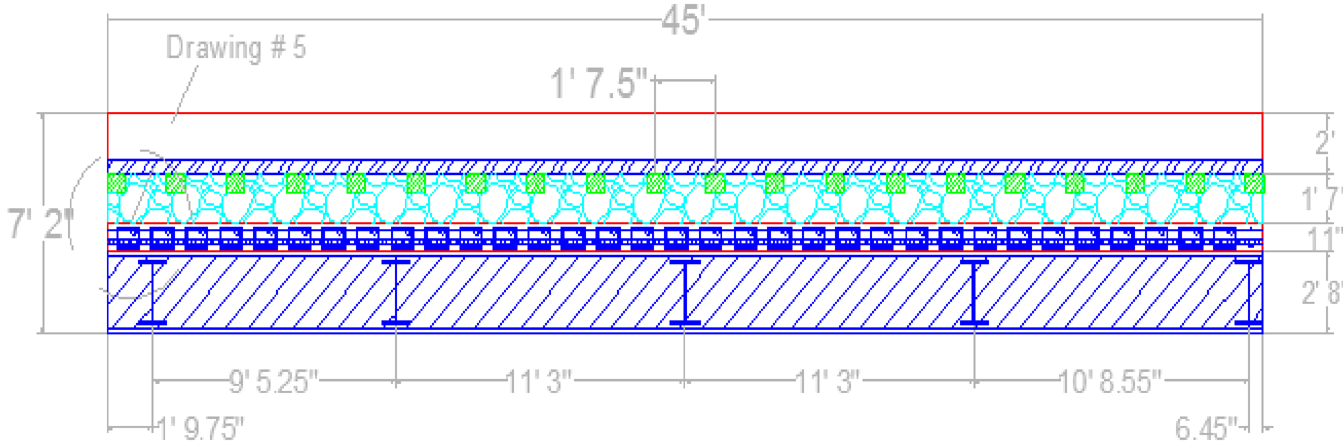

Figure 36 Drawing #4: Longitudinal View of Superstructure

Since the lateral design governed, the longitudinal design is based on a percentage of the lateral reinforcement. This reinforcement will consist of the same members and the percentage will be applied to the spacing. This resulted in the members being spaced ten inches on center. The reinforcement will be placed in-between the lateral reinforcement so they are just touching, but not so as to rest upon the lower bars. Ideally this would create a tangent line where they touch, however realistically the spacing may be a little off. The top longitudinal bars will extend beyond the forty-five-foot superstructure, into the substructure and extend until they come within three inches of the substructure reinforcement. The bottom bars will run down into the substructure five inches below the top of the wall, extending past the forty-five foot deck. With the reinforcement designed the superstructure design is complete.

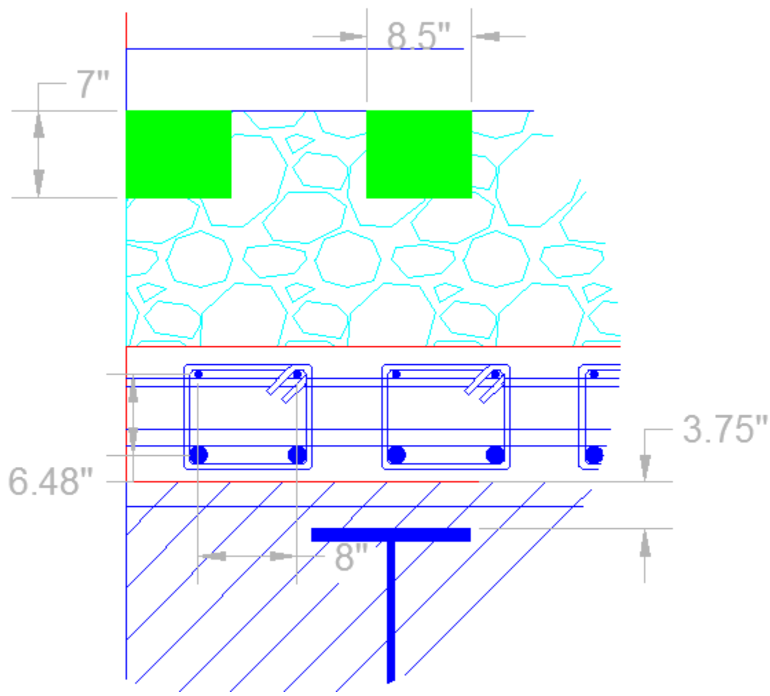

Figure 37 Drawing #5: Reinforcing Detail from Longitudinal View

The group also investigated alternatively using Hillman Composite Beams (HCB) instead of the structural steel stringers. A thorough design was not completed due to time constraints, so the rest of the Commuter Rail underpass design does not take the HCB design into consideration. The HCB design is presented below in figure 38. The beam consists of a fiber reinforced plastic shell, tension reinforcement, a concrete arch, shear connectors, and a low-density foam core that surrounds the material (not shown). The major difference between the general design process of the stringers and the HCB is that the HCB design requires composite action, which this project did not consider. The alternative design provides some clearance due to the composite behavior and eliminates the need for lateral bracing, due to an increase in the number of beams required. The HCB offers a lightweight alternative beam, which reduces the cost of material. Overall a further analysis would need to be completed to determine whether or not the HCB would be a good application for this bridge.

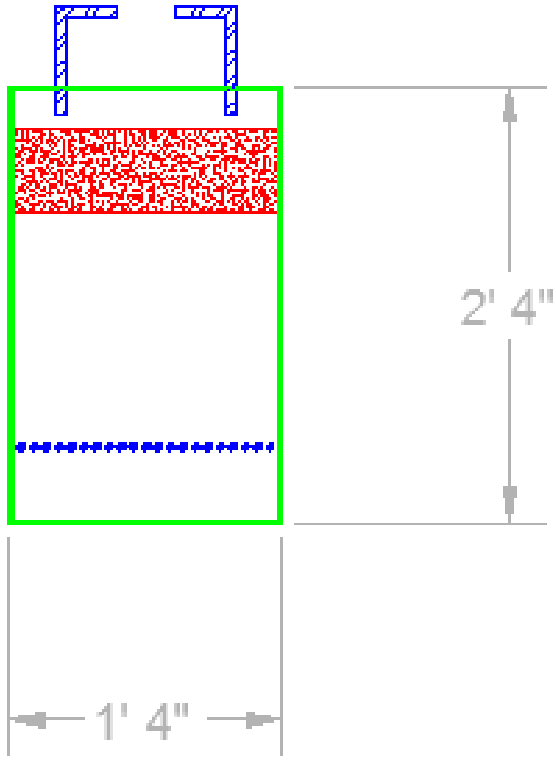

Figure 38 Cross Section of the HCB

The design process for the superstructure involved designing the stringers, lateral bracing, and the reinforced concrete deck. For each approach, initial member sizes were assumed in order to approximate loads and properties. Using this approach required previously selected members to be checked to insure that newer members weren't conflicting with initial assumptions. With the superstructure design complete, the next phase of the project design is the substructure.

8.3 Substructure

As outlined in the Methodology, the design of the substructure consisted of designing the retaining wall abutment and the footing. Sequentially, the design process required initial assumptions for the semi-gravity wall in order to analyze the wall's ability to resist overturning moments caused by the earth pressure behind the wall. This analysis looked into three separate cases that could cause failure. The first case looked at the initial active earth pressure immediately after installation, prior to the superstructure being superimposed on the substructure. The second scenario investigated the earth pressure caused by a train loading surcharge located just to the side of the superstructure. The third scenario investigated the pressure created by the earth and breaking load of a train on the superstructure. The third scenario governed the design and thus primarily increased the thickness of the wall. Following this analysis, the final Substructure design is presented below in Figure 39.

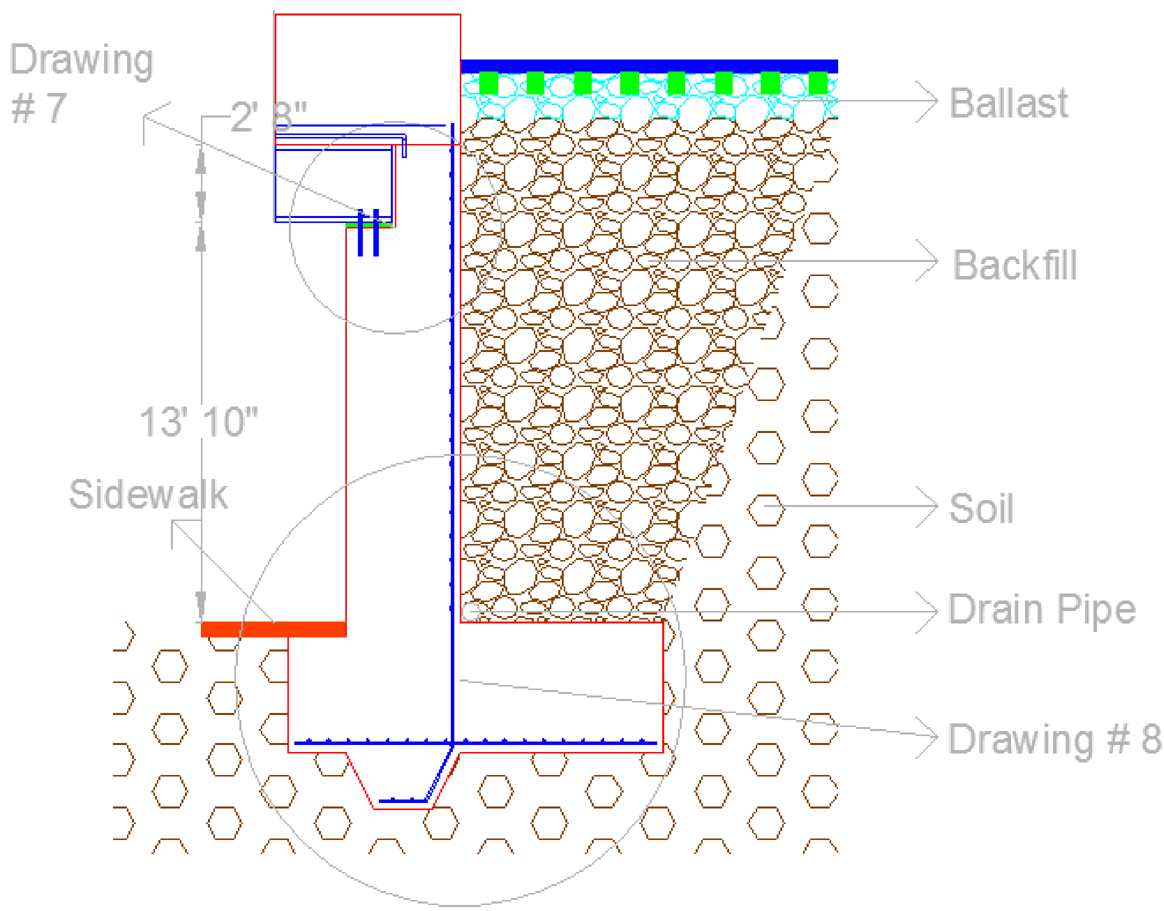

Figure 39 Drawing #6: The Substructure

The overturning force caused by the earth pressure is based on the assumption that the backfill will consist of a relatively dense soil. Keeping this in mind, the ballast and backfill are designed so as to permit water to easily travel through these layers so that it does not cause a backup on the tracks, or behind the substructure. Since the water created by rain/snow will travel relatively quickly through this material, a drain pipe has been placed at the bottom of the backfill so as to permit the water to flow out and not build up behind the wall. If the rain were to build up it could cause excessive overturning forces to develop. Another assumption made is that the water table is not located above the bottom of the footing; if this were the case, it would increase the forces present on the wall and could cause the wall to overturn. Additionally the footing needed to be a certain depth so as to penetrate the deepest frost lines expected near Boston, MA which happened to be approximately four feet below ground level (AREMA 2000). To detail this and Figure 39 above, the summary of the design is presented below in Table 13.

Table 13 Substructure Components

Substructure	Members
Cast in Place Concrete Wall and Footing	Standard Construction Concrete (5 ksi)
Retaining Wall:	
Vertical Support (Including Extension into Footing)	#8 Reinforcing Steel Bars
Lateral Support	#7 Reinforcing Steel Bars
Footing:	
Horizontal Support	#10 Reinforcing Steel Bars
Lateral Support	#8 Reinforcing Steel Bars

With the dimensions of the retaining wall determined the proceeding step was to determine the reinforcement required. For a semi-gravity wall, reinforcement is only needed in the backside of the wall to resist the bending stresses caused by the overturning moment. With a thickness of four feet the front side of the wall will have a sufficient moment of inertia to resist bending stresses created by the train and earth. Through an investigation it became apparent that the amount of required steel would be based upon the maximum reinforcement allowed per linear foot of wall. This led to the selection of #8 bars spaced eight inches on center for vertical support. The vertical supports are covered three inches from the wall to the backfill/earth located behind it. The lateral reinforcement is secondary to the vertical support; so similar to the deck design, this will be taken as a percentage of vertical reinforcement, and be located in front of the vertical reinforcement. Thus, the lateral reinforcement will consist of #7 bars spaced eight inches on center. The vertical supports run from the lower section of the footing up into the deck to the highest point of the top deck reinforcement. The reinforcement along with some of the superstructure connections is detailed below in Figure 40.

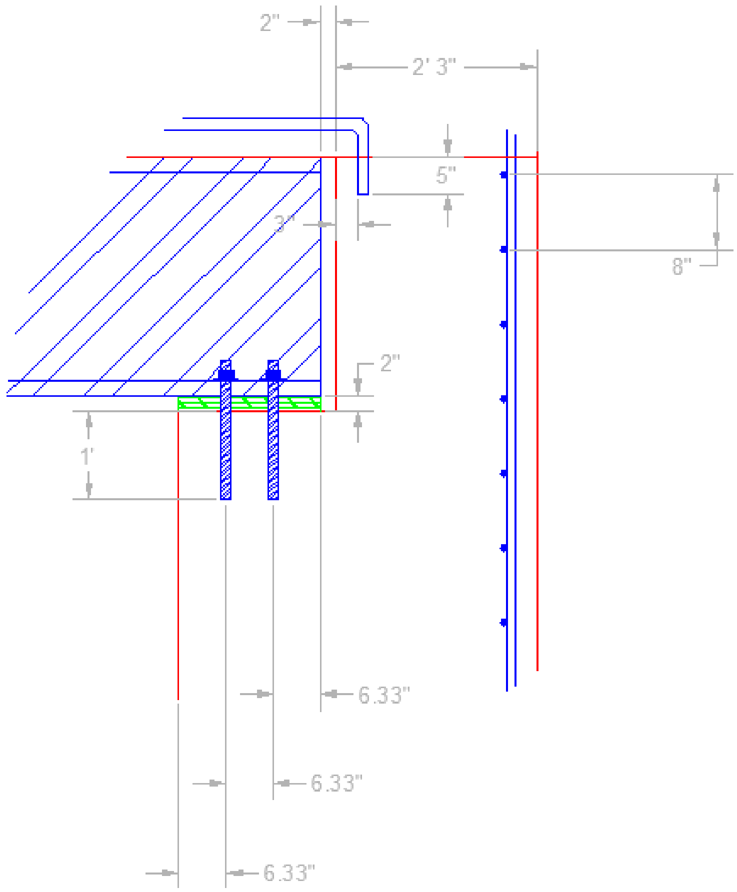

Figure 40 Drawing Number #7: Top of Retaining Wall Abutment Design

Reinforcing the strip is similar to reinforcing the wall. The lateral support is secondary to the longitudinal support and is based upon the maximum allowable reinforcement per linear foot. Thus, the required reinforcement in the longitudinal direction consists of #10 bars spaced eight inches on center, and the lateral support consists of #8 bars spaced eight inches on center. This support is the same in the lower part of the footing. This lower part provides the footing with additional resistance against sliding, which is detailed below in Figure 41.

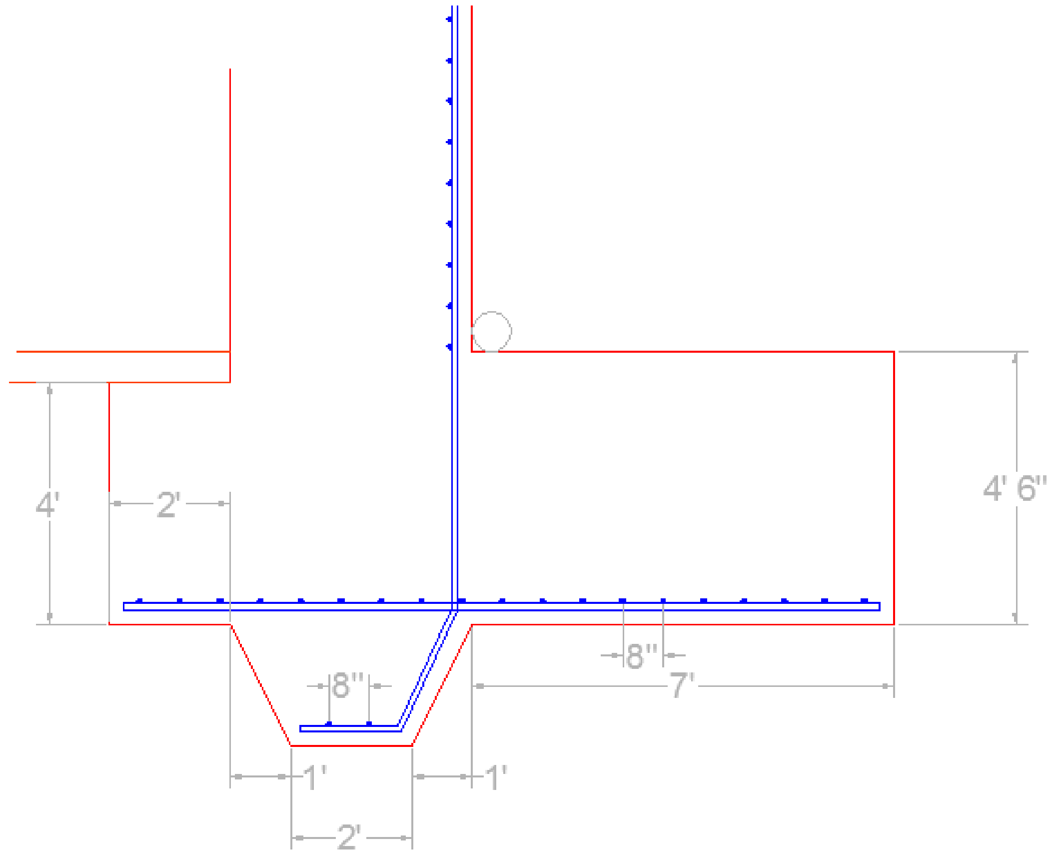

Figure 41 Drawing #8: Detail of the Footing

Resistance against sliding, settlement, and soil bearing capacity are three areas of interest that are not addressed in this project. Before any project begins the engineer needs to conduct a geotechnical investigation and determine the soil properties and the location of the groundwater table. Resistance against sliding will be based upon the frictional force present between the footing and the soil below. The soil bearing capacity will need to be large enough so as not to cause the wall to fall into the ground in the immediate vicinity. Investigating this will be based upon the bearing capacity nearest the sidewalk/roadway. In addition to this, the bearing capacity needs to be investigated to ensure the entire wall will not cause a slope slip failure either. If the water table is close to the foundation, or the soil permits extensive settlement, the engineer may determine that this shallow foundation will not be sufficient and a deep foundation design may be required. An initial deep foundation design requires knowledge of the water table and soil layers, so this was outside of the scope of this project.

Overall the substructure design investigated the wall's resistance to overturning, and the reinforcing detail in the substructure. The next phases for the substructure design process will be to obtain the geotechnical reports and work with the design from there investigating the different modes of failures that could occur. With the substructure designed, the next phase will be designing the connections of the superstructure and substructure.

8.4 Bearing Pad Design

The superstructure will be connected to the substructure through the use of bearing pads and bolted connections. The deflection of the stringers, thermal expansion, and the bearing pressure placed on the pads determined the dimensions of the bearing pads. Through this investigation the team determined that the stringers would rest upon neoprene bearing pads with the dimensions of 16" x 19" x 2" on the pin connected side and 29" x 19" x 2" on the roller connected side. The bearing pads with the stringers resting upon them can be seen in Figure 42 below.

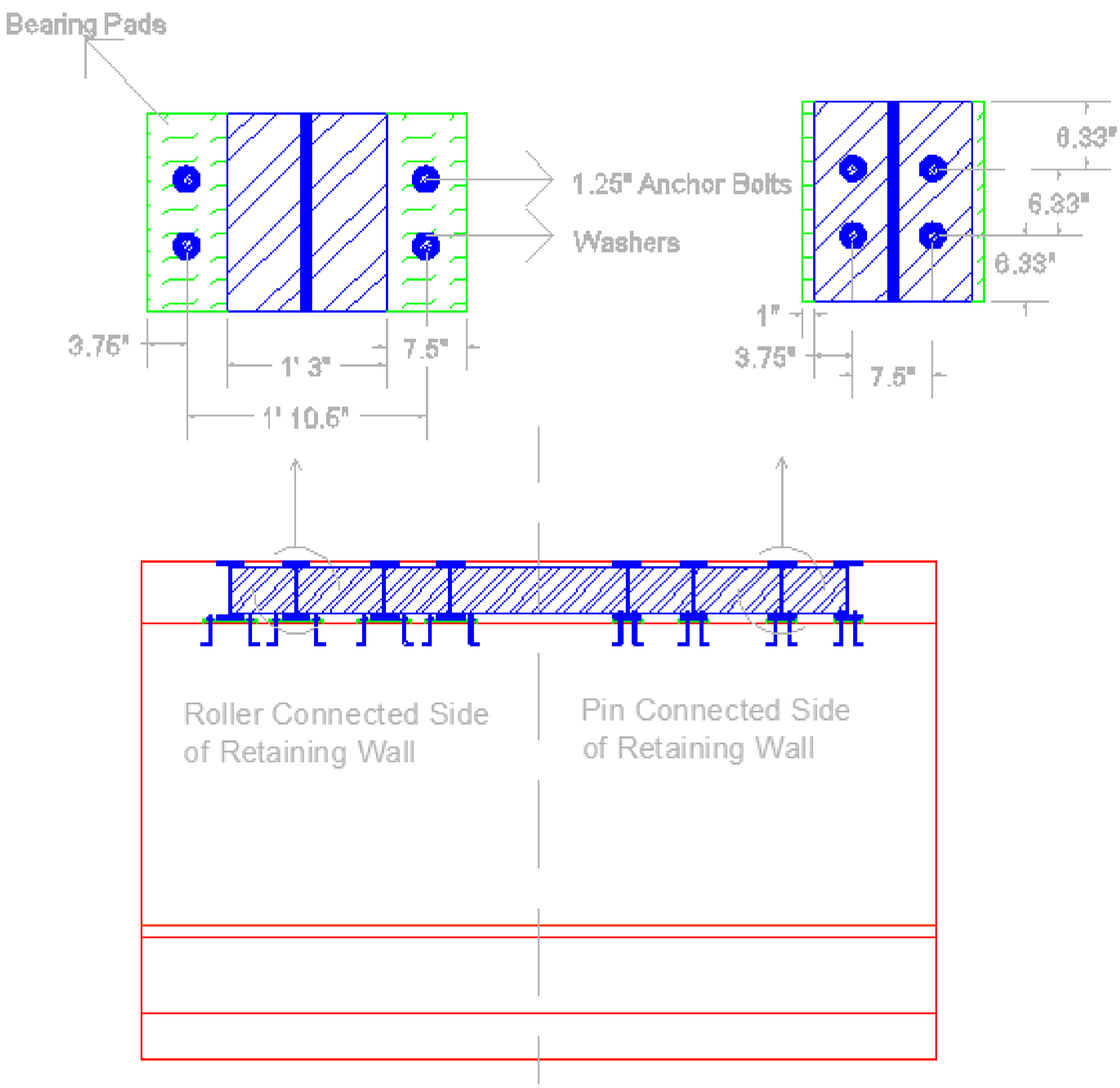

Figure 42 Drawing #9: Connection of the Superstructure and Substructure

The bottom part of the figure shows the substructure as viewed underneath the superstructure and the figure illustrates two halves of the different walls. One wall will consist of all pin connected members, and the other wall will consist of all roller connections. On the roller connected wall, the stringers will rest, unbolted, on top of the bearing pads. The bearing pads are bolted into the wall with 1.25" diameter bolts that extend a foot into the wall and are jetted out on each side 5".

The pin connected wall has these same bolts drilled through the stringers, allowing the use of smaller bearing pads.

8.5 Cost Estimate

The cost estimate is based on the 2009 edition of *RSMeans Heavy Construction Data* and the average inflation rate since the beginning of the twenty first century (Spencer, 2008). The cost estimate is divided into the different stages of the project, and at each stage different items are identified for a cost analysis. The cost estimate is presented in Table 14 below, and the year based adjustment for inflation is presented in Table 15.

Table 14 Cost Estimate

Item (Major Components)	Cost Estimate (Includes Material, Labor, Equipment, 10% Overhead and Profit)
Planning, Scheduling, and Office Expenses	$157,000
Geotechnical Investigations	$2,275
Site Preparation and Storage (Not Including Temporary Rails)	$18,600
Demolition (Tubes, Roadway, Sidewalk, Excavation, and Rail Tracks)	$18,100
Substructure (Cast in Place Footing, Retaining Wall, Backfill and Compaction)	$88,000
Superstructure (Precast Concrete Deck, Steel Stringers, Lateral Bracing, and Paint)	$410,000
Site Clean Up, Opening up the Tracks and Roadway	$9,075
Miscellaneous Costs (Insurance, Sales Tax, City Adjustment Cost, and Quality Control)	$201,000
Grand Total (Rounded Up)	**$905,000**

The first item presented is planning, scheduling, and office expenses. This estimation is based on different percentages of the subtotal cost of material and labor for the entire project. The cost for the General Contractors and Main Office Expenses controls this cost, and it typically represents about 10 percent of the cost of the entire project. (Spencer, 2008) The geotechnical investigation is the next component represented, and it is a small portion of the cost but an important part of the process. This stage of the process provides information on the ground conditions and ultimately controls the direction of the project. Assuming the investigations come back favorable, the rest of the estimations represent the physical cost of the project.

The first phase of the physical project is to set up the site and prepare the appropriate locations for storage. The demolition component represents the demolition and removal of the track, ballast, Tubes, sidewalk, pavement, and the cost of excavation. With this complete the site is ready to have substructure installed. This estimate is based on the labor and material costs for the footing, the wall, the backfill/earth, and the compaction of the earth. The cost of the footing and the wall are the most expensive components of the substructure and represent almost 10% of the project cost.

The cost estimate of the superstructure is almost half of the project's total construction cost. There are a few reasons for this significant impact on the cost. This section includes the cost of the stringers, bracing, deck, the connections between all of these pieces and the cost of painting the steel. The cost of the stringers is the single most expensive item, making up about 25% of the cost of the entire project. The stringers are composed of high strength steel, and require a special cost to install due to their weight. Besides this item the precast concrete deck also adds significantly to the superstructure cost.

After the superstructure is complete the concluding stage of the project consists of reinstalling the tracks, sidewalk, street, and cleaning up the site. The final item presented is the miscellaneous costs, which includes: sales tax for material, insurance and social security for the workers, the city cost factor, and regulatory plus quality control checks. The city cost factor increases the cost of the project by almost 10% due to the high cost of construction near Boston, MA, compared to the rest of the United States. With an estimate for the cost of the project, the next step is to adjust the cost due to inflation, which is presented in Table 15 below.

Table 15 Cost Estimate Adjusted for Inflation

Year	Estimated Final Cost Based on Inflation
2009	$905,000
2012	$971,500
2017	$1,095,500
2022	$1,219,000
2032	$1,654,000

Since the cost estimate is based on data from 2009, the group adjusted the cost to 2012 and projected the cost in five or ten year increments afterwards. 2009 and 2010 were slow years for inflation rates; however they have seemed to recap in 2011 and 2012 so far (Current Annual Inflation Rate, 2012). Averaging these values, the 2009 price is adjusted to 2012 (rounded to the nearest $500). The analysis past 2012 involved averaging the inflation rate from 2000 to the present. This method determined an average inflation rate of 2.55% (Current Annual Inflation Rate, 2012). With this average value, the table projects the cost of this design five, ten, and twenty years from now.

This cost analysis only projects the initial construction cost of the project. The life time costs are an aspect of the cost not investigated due to the unpredictability of the cost multiple years down the road. The lifetime costs would include reballasting the track, re-painting the steel, and spot concrete patching. Outside of this, the cost could depend upon the cost of any natural or manmade accidents, or other uncertainties. In addition, the prediction of inflation used above becomes less accurate over time. Keeping the accuracy of this in mind, the projected cost for the project today would be around $971,500 and five years from now it will be just over one million dollars.

The group took multiple ideas into consideration to reduce the cost of the project. The first idea was to recycle the track, ballast, and earth currently being used to reduce the cost of the material. Another plan was to detour the traffic around the construction site so as to not affect the time of construction, which indirectly would increase the cost. The third plan to reduce cost was to increase the time efficiency and shorten the duration of the project which will be discussed in the next session.

8.6 Time Estimate

The time estimate is based on the predicted time for completion of each task using the 2009 edition of *RSMeans Heavy Construction Data*, similar to the cost estimate (Spencer, 2008). The time estimate groups together different tasks within five major phases of the project: Geotechnical Investigations, Demolition/Site Preparation, The Substructure, The Superstructure, and Site Clean Up. Figure 43 below represents the different phases of the project in a Gant chart.

ID	Task Name	Duration
1	**Project Begins**	0d
2	Borings & Initial Field Stake Out/Elevations	1d
3	Drawings for Boring Details	1d
4	Report & Recommendation from Engineer	1d
5	Remove Tracks & Ballast	1d
6	Site Preperation	1d
7	Remove Tubes	1d
8	Excavate Backfill/Land	3d
9	Remove Pavement & Sidewalk	1d
10	Cast in Place Concrete Footing	2d
11	Cast in Place Concrete Retaining Wall	6d
12	Concrete Hardening	20d
13	Install Neoprene Bearing Pads	5d
14	Installing & Compacting Backfill	4d
15	Installing Stringers	7d
16	Installing Lateral Bracing	7d
17	Installing Precast Concrete Deck	14d
18	Cleaning, Preparing, and Painting Steel	3d
19	Reinstalling Roadway & Sidewalk	2d
20	Reinstall Ballast & Tracks	1d
21	Site Cleanup	1d
22	**Project Ends**	0d

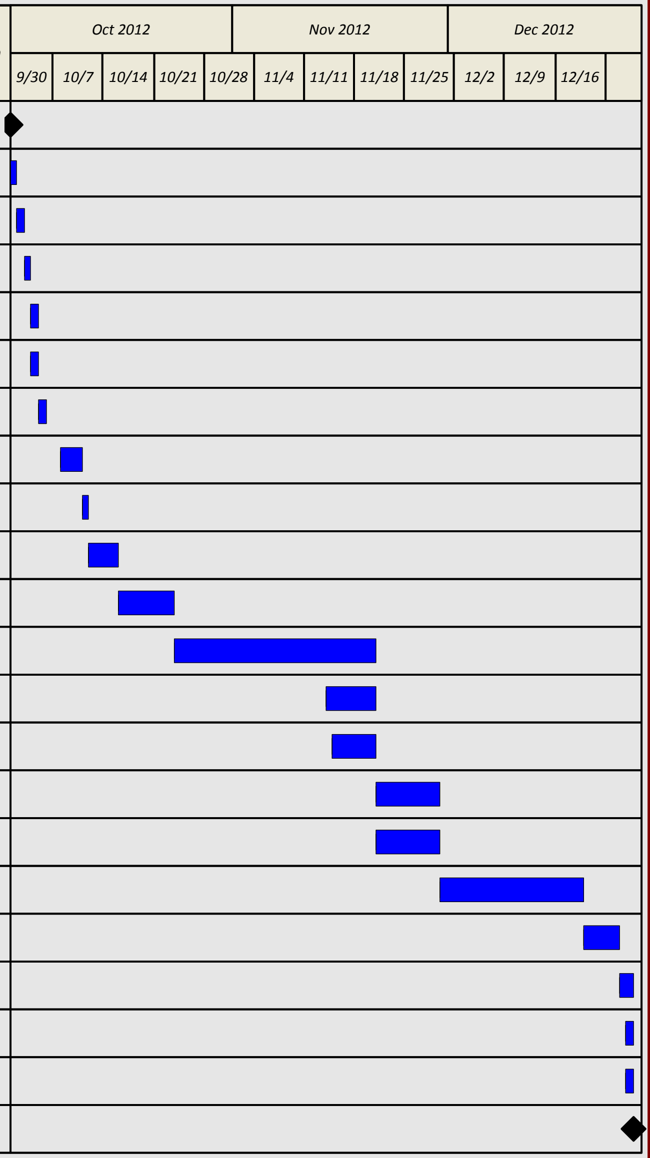

Figure 43 Time Estimate for Construction of Underpass

The overall time estimate for completion is seventy one days. If the work schedule included weekends, this would create a project that lasts about two and a half months. If weekends are not utilized, then the projected time of completion would be about three and a half months. Either way, these would impact the cost in different manners and should be further investigated. These estimates assume normal eight-hour days. Each estimate shown above is an overall grouping of tasks, and each yellow section consists of multiple projects going on simultaneously. There are a few ways to decrease the time of construction.

The group took multiple ideas into consideration to reduce the time of construction. These included a pre-cast concrete deck, and the simultaneous completion of certain tasks like placing the bearing pads and earth on/around the substructure while it has not quite reached its 28 day strength. Some other methods to decrease the time of the project would be to mix different admixtures into the concrete to increase the curing rate, working through the night, and hiring more workers to weld and paint the steel components of the structure. The reason the group did not take any of these into considerations is due to the fact they all increase the cost of the project. If dealing with the train detour proves to be a real challenge, then all of the above and more may be a viable solution to deal with this. The train detour, along with the rest of the construction phase is discussed below.

8.7 Construction Phase

The construction phase involved laying out the site storage plan, determining a site plan, and re-routing the Commuter Rail line. The site storage plan lays out potential areas for storage of excavated backfill, structural members, rail ties, and identifies construction vehicle access. The vehicle detour provides alternative routes into the Inner Belt Core (IBC) and the businesses located within the IBC. The Commuter Rail plan provides two alternatives for re-routing the train. These three components compose the construction phase and provide a means to construct the underpass safely and in a timely manner.

8.7.1 Site Storage Plan

The site Storage Plan consists of two locations for construction storage (Approximately 10,000 square fett), and two for rail line storage. As seen in Figure 44 below, the rail line storage is located west and east of the Tubes, on the existing rail lines. Due to the length of the tracks and the uncertainty of their exact size and location of the current tracks, the group decided that placing these members next to the existing track would be ideal, and an allowance for size could be accommodated here. The rest of the storage will be located North and South of the Tubes. This is due to the fact that if too much material is stored east and west of the tubes, a collapse may occur on the open earth excavation site. Since the materials will be delivered from the North, the roadway on that side of the Tubes will need to allow construction vehicles in and out easily. Thus, a majority of the items that need long term storage, such as ballast and backfill will be pilled south of the Tubes. The north side will consist primarily of steel members, cranes, trucks, and other material that will only be stored on site for no more than a few days. All of the local businesses will have access to their buildings and parking lots, except for the business on the South East corner of the map. Chapter 8.7.2 will identify alternative routes and address this problem.

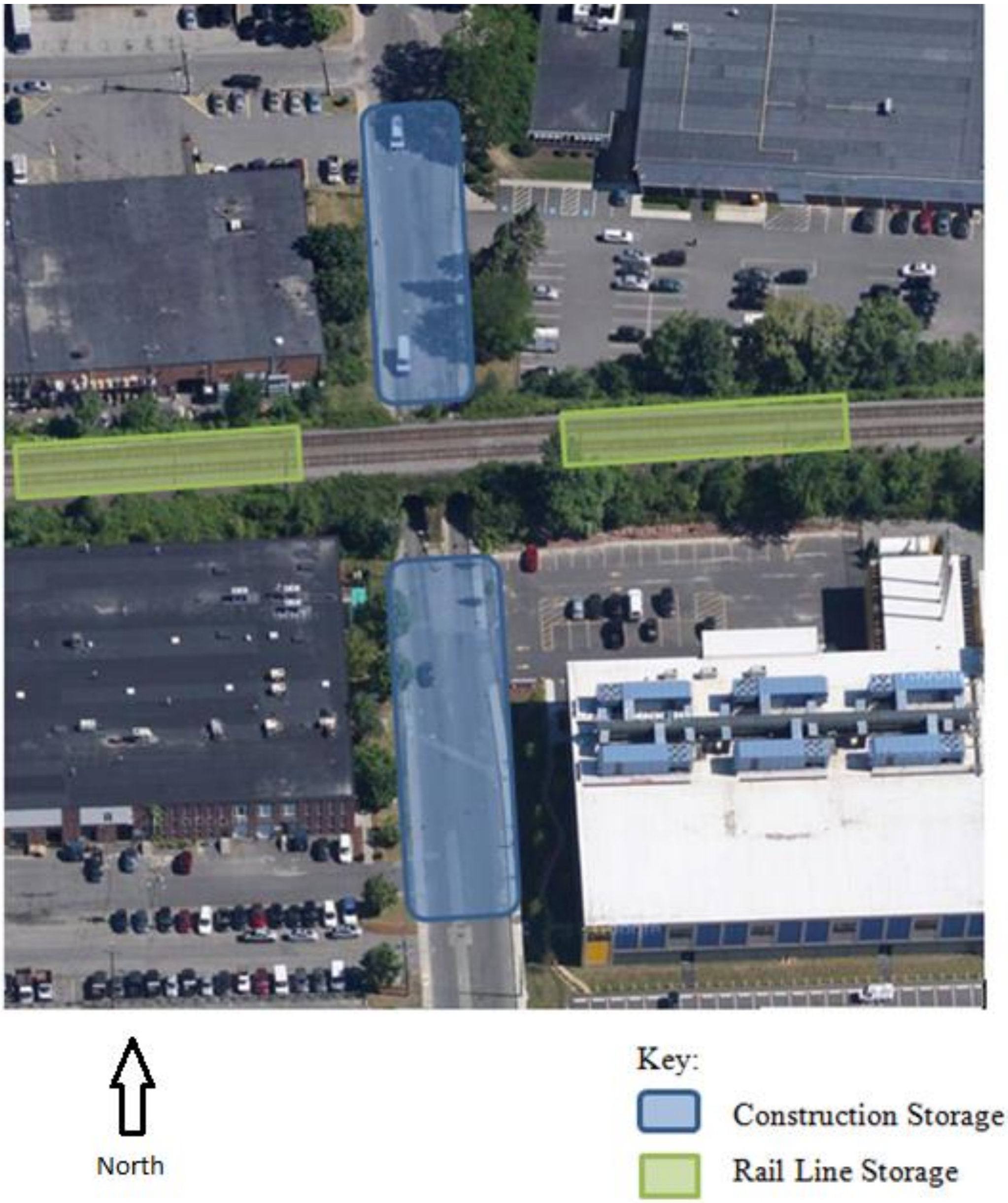

Figure 44 Site Storage Plan

8.7.2 Vehicle Detour (120x40*2)

The team investigated two separate options for a vehicle detour. The first option considered was to do the demolition and construction at a reduced speed and allow one lane of traffic through. This type of plan increased the time needed to complete the project, and thus indirectly increased the cost of it as well. The group learned of an alternative entrance into the IBC, which is not a normal through route but provides an entrance to the area for the police and fire personnel in case of an accident in/South of the Tubes that would prevent entrance to the area otherwise (personal communication, Stephen Mackey, October 15, 2011). As outlined in green on Figure 45 below, the vehicle detour comes from the North on Inner Belt Rd, turns east onto a side street, loops around the buildings in the north east corner, travels under a train bridge, and connects back into Inner Belt Rd through Third Ave. The red lines on the figure identify the alternative routes for businesses closed off by the barriers.

Figure 45 Vehicle Detour Route

The businesses on the south west corner will have access by using this detour route and entering through the parking lot below the orange barrier. The businesses on the northwest corner will have access through New Washington Street (shown in red on the upper left hand corner of the figure). This route extends beyond the scope of the map, but turns onto Cobble Hill Rd, and enters from the west. The businesses on the north east corner will enter through the red line shown, which is located approximately half way through the detour route. The only business that will lose some parking through this detour, is the business located just south east of the Tubes. The lot is located within the barrier and there is no other access point. An option for the businesses impacted is to park in the adjacent lots. All of the businesses south of the Tubes will have access through this alternative route and it will allow for an uninterrupted construction of the Tubes.

8.7.3 The Commuter Rail Plan

Dealing with the Lowell Commuter Rail Line proved to be the most challenging aspect of the construction phase. Trying to keep the Commuter Rail open during construction is not feasible as there is no inexpensive way to do this. Shutting down the train between North Station and West Medford Station will cut off access to and from Boston on the Lowell line. With thousands of passengers inbound to Boston on an average weekday, three alternative routes were investigated. The first alternative considered bussing people between West Medford and North station, since there are no other train stations reasonably close to West Medford. It became apparent that the amount of busses required, and the time to ship people between these locations would be inefficient. The biggest problems with this alternative were the unknowns, such as the role traffic would play, determining how many buses would need to be supplied from the MBTA, and how this would affect traffic. Overall, this type of alternative would require extensive data collection. The group felt this plan was not a feasible one.

The second and third option the group investigated, involved installing new track to detour the Lowell line. The second alternative requires only one location for new train lines to be installed, assuming the rest of the tracks are acceptable. The path selected is highlighted below in Figure 46. Upon investigation of various maps, the group noticed there are multiple locations upon the track where it is possible to jump the train between tracks. These locations require a switch to be pulled allowing the train to be redirected down a different path.

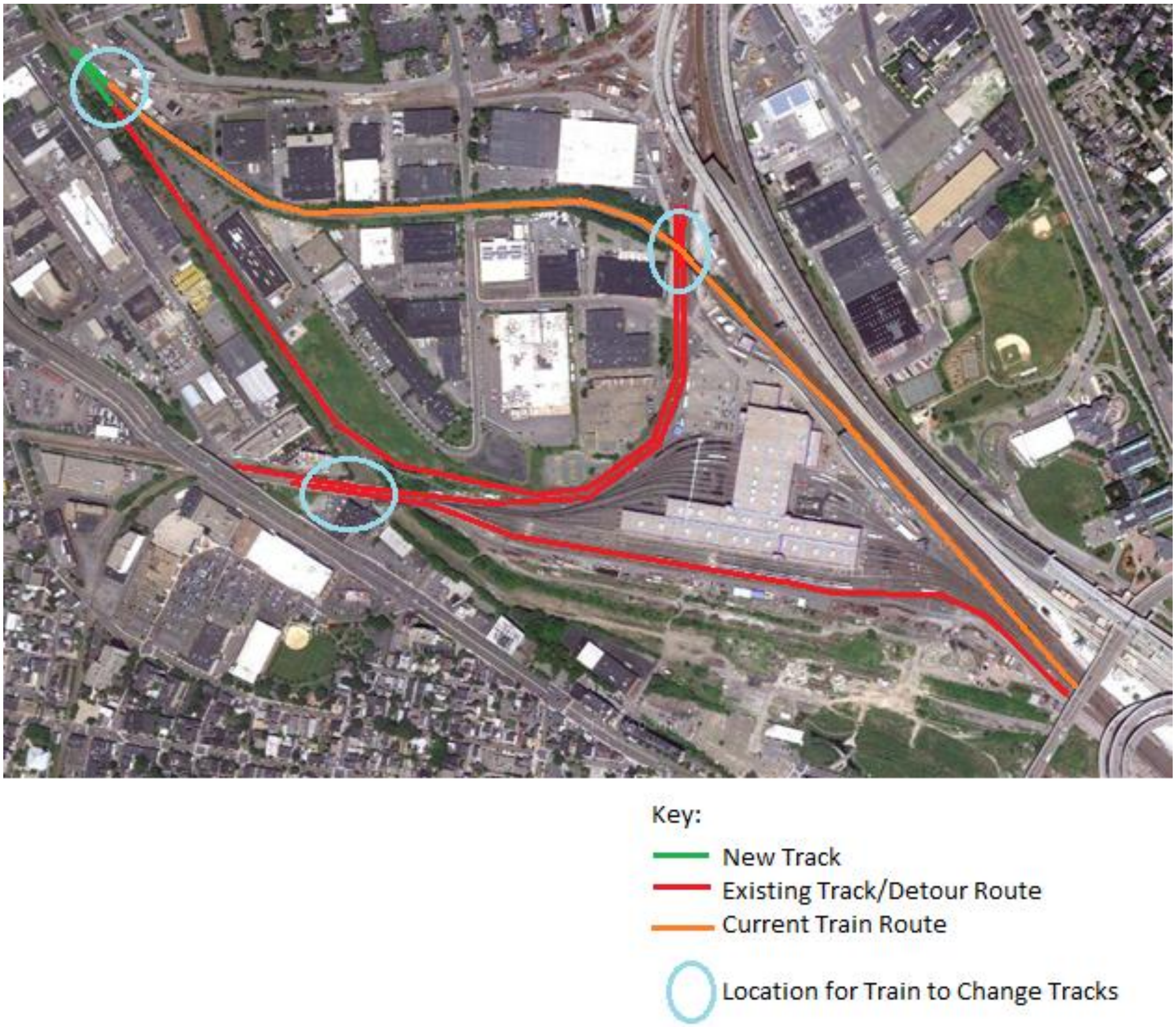

Figure 46 Alternative Train Path

In order to explain the Figure above, let's assume that a train is coming from the West Medford Station (The North West region of the map). The train would need to either swap onto or be on the lane farthest west, since there are two tracks on the Lowell Line in-between West Medford and North Station. From this lane the track would travel off of the standard Lowell Line (the orange path) onto the green path shown, which would be the newly installed track. The train would travel onto the red path, which consists of existing track. The train would travel north and swap onto the Fitchburg line as shown by the blue circle. From here the train would need to come to a stop and start travelling in the opposite direction, requiring the trains to have two separate engines on each end of the line. From here the train would travel to the area highlighted with the blue circle where it would stop, reverse direction, and change over a track. From this point on the train would follow the red line on the southern part of the figure and would jump tracks as it heads towards North Station and would eventually be on the original (orange) Lowell line. A train travelling out of North Station would follow the same path in the opposite direction.

The third alternative investigated installing a connection track from just north of the southern blue circle; this track would travel across all of the tracks to the red line on the southern part of the map. This alternative would cut out the need for the trains travelling through to turn around twice. The problem with this design is that it would require the installation of more train tracks and would require a small bridge to transfer the train. The team felt this would unnecessarily raise the price of the project. So alternative two appears to be the best choice; however there are multiple issues this alternative raises. The first is that if the MBTA approves a project like this, it would need to be done before the Green Line Extension. Additionally, forcing the train to turn around twice increases the time of travel and interferes with other train lines. Not to mention that only one train could travel this pathway at a time. Determining how this would work was out of the scope of this project; however these are the initial problems the group identified. Overall re-routing the train line is not a simple process and could prove to be one of the more challenging aspects of the Commuter Rail Underpass installation process.

8.8 Summary of Commuter Rail Underpass Design

The Commuter Rail Underpass design involved the design of the superstructure, substructure, a cost estimate, a time estimate, a site storage plan, a traffic detour plan, and a train re-routing proposal. The superstructure and substructure design followed AREMA guidelines and provided multiple structural designs presented with the use of AutoCAD. The cost estimate determined an overall cost of $971,500. The time estimate projects a completion time of approximately two to three and a half months. The construction phase found a location for site storage, a detour plan, and suggested an idea to re-route the Lowell Commuter Rail Design. A three dimensional Google Sketch Up of the Commuter Rail Underpass is presented below.

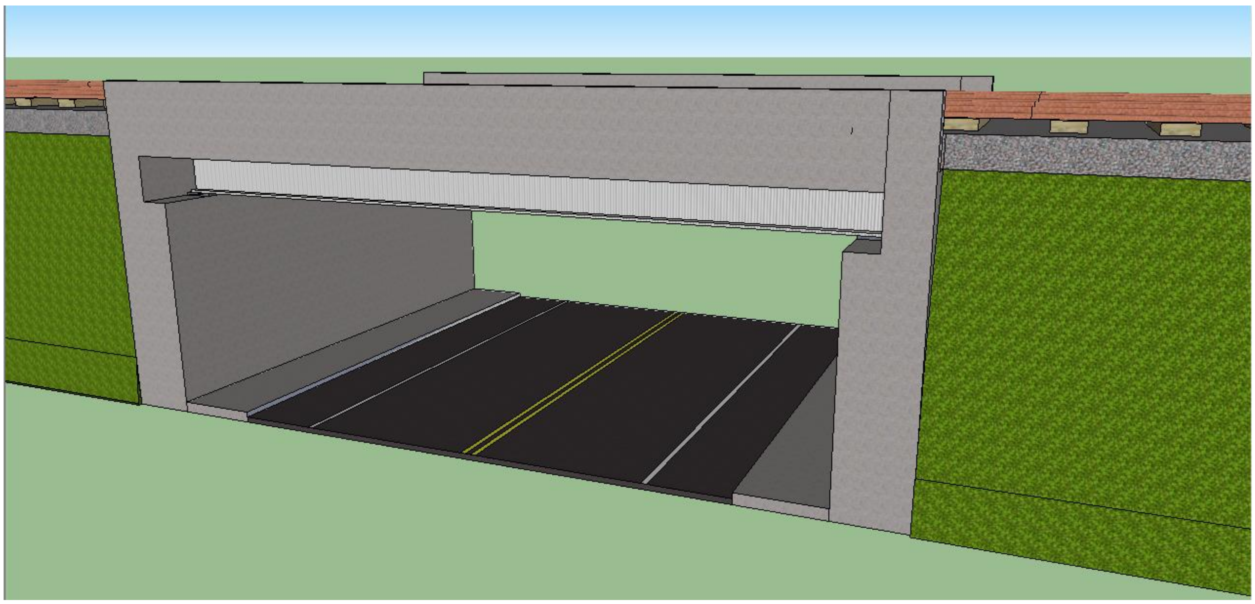

Figure 47 3D view of the Commuter Rail Underpass

(Railroad tracks object imported from the Google 3D Warehouse)

9.0 Redevelopment Transition Plan

The purpose of this chapter is to provide an overview of different considerations regarding the redevelopment of the area as it transitions from a light industrial neighborhood. The chapter discusses land use controls and economic aspects of redevelopment. Section 9.1 describes various land use controls needed to shape redevelopment in order to achieve vision outcomes that meet the design guidelines. Section 9.2 discusses market feasibility in terms of financial and regulatory means of encouraging development. Section 9.3 addresses additional economic considerations with regard to infrastructure improvements.

9.1 Land Use Controls

Land use controls are regulatory or non-regulatory means of shaping, or controlling, the types and details of development that occurs on an area of land. A common land-use control is basic zoning, but other kinds of plans and policies may be used such as those for Planned Unit Developments, especially when attempting to achieve specific or complex outcomes, as is the case for this vision (Burke, 2009).

In land use planning at the city level, community-defined vision and community consensus on community values is important. Considerations for municipalities for design guidelines include site design, architectural design, protecting unique character and heritage, etc. Visual preference surveys, as used at the Inner Belt/Brickbottom planning meeting attended by the project team, are considered useful planning tools for soliciting community attitudes and understanding what images communicate their values and vision.

As mentioned in Section 6.3 of this report, The City of Somerville has experience with ongoing mixed-use redevelopment in the Assembly Square Mixed-Use District. Doubtless, this area will serve as a model for development in the Inner Belt Core, though these two areas have unique challenges and several differences. The Somerville Comprehensive Plan is currently in the process of being developed and will provide another source of land use controls for redevelopment.

As for planning for sustainability, *Land-Use Planning for Sustainable Development* by Jane Silberstein and Chris Maser is a helpful text that examines land-use planning in the context of sustainability. Chapter 6, “Implementing the Comprehensive Plan,” considers zoning, other regulatory and non-regulatory methods of land use control in the context of sustainable development. It examines design and desirable aspects of design, providing rationale. Open space is beneficial due to “human need for contrast in one’s built environment, such as passive spaces to serve as a welcome relief from the built environment,” and it also-enhances property values. Landscaping is desired to control stormwater, beautify a site, and heighten property values. Desirable design controls include site design, architecture, signs, and graphics.

The text also goes into great detail regarding ideas to redesigning zoning ordinances (also defining the tool) for sustainable development, such as requiring a full range of innovation in technology in eco-parks, as a hypothetical example. It recommends incentives as opposed to requirements in some cases, citing places where developers and encouraged to improve quality of life in a community through affordable housing, parks, improvements in infrastructure, childcare facilities, public art, etc.; these examples could be researched and incorporated into the WPI project team’s design for redevelopment in Inner Belt. A chapter on incentives goes into detail on different kinds of incentives and their effectiveness, emphasizing not only traditional tax advantages, actual payment to landowners, allowing higher-than-usual building densities on land for increased densities, etc., but also “rewards in the form of community recognition.” Such community recognition could be given through awards presented by an official or unofficial Beautification Committee, which could recognize and publicize acts such as maintaining “a lovely flower garden,” painting, or using appropriate signage. Fiscal impact analysis, environmental impact analysis, and checklists for sustainability are also discussed and recommended.

Specific land use plans can be found in the *Commercial and Mixed Use Development Code Handbook* of the Oregon Transportation and Growth Management (TGM) Program. This handbook contains objectives, supporting plans and policies, and best practices for “smart” development in line with that envisioned by the project team in Inner Belt Core. The TGM Program promotes congruent goals such as compact development, mixed land use, housing variety, pedestrian-oriented streets, security, public space creation, efficient parking, and human-scaled building design. Oregon recommends achieving these goals through a number of strategies executed via plans and ensuing policies:

- comprehensive plans
- specific area plans
- local street and sidewalk plans
- capital facilities plans (CFPs) and capital improvement plans (CIPs)
- transportation system plans

The following subsections provide elaboration each of these five types of plans.

9.1.1 Comprehensive plans

Comprehensive plans implement development via policy language and plan maps. Plans need to encourage mixed-use development by permitting a complementary mix of land uses in close proximity to one another. Additionally, comprehensive plans can direct future development to provide essential street connections needed in the Inner Belt Core. According to the Oregon TGM Program, both local governments and the private sector are looking for ways to encourage more transportation-efficient development by updating comprehensive plans (Oregon TGM Program, n.d.).

9.1.2 Specific area plans

Mixed use development "can be difficult when neighbors' concerns about traffic, parking, noise, building design, and other compatibility issues, outweigh the merits of the proposal. A specific area plan can help in addressing neighborhood issues." They "provide a policy framework for land use, transportation, and public improvements, and may include design guidelines, overlay zones, and public amenity requirements. They are developed through a public planning process that involves property owners, neighbors, and the local government" (Oregon TGM Program, n.d.).

9.1.3 Local street and sidewalk plans

Local street and sidewalk plans "can help to ensure that vital transportation connections are made as land develops" (Oregon TGM Program, n.d.). Transportation plan maps are relevant for the redevelopment transition for future street and sidewalk connections to Brickbottom and North Point, local street plans for the Inner Belt Core's overall street grid, and sidewalk plans for the street grid. The City of Salem's Sidewalk Construction and Management Plan provides an example of a local sidewalk plan (Oregon TGM Program, n.d.).

9.1.4 Capital facilities plans (CFPs) and capital improvement plans (CIPs)

Capital facilities plans (CFPs) and capital improvement plans (CIPs) "prioritize, and direct or guide, the timing and location of needed infrastructure" (Oregon TGM Program, n.d.). In the Inner Belt Core, such plans could be used to provide timelines prioritizing the construction and associating financing of the project team's various infrastructure recommendations. Infrastructure improvements requiring planning include a new Commuter Rail Underpass, for which a preliminary cost analysis was provided, a redesigned Inner Belt Road main throughway, and pedestrian and vehicular connections to adjacent neighborhoods. Additional infrastructure improvements will likely need to be addressed in conjunction with redevelopment, such as include water and sewer lines and the stormwater system. Some improvements may be deemed low priority or too expensive to be fiscally feasible at this time, while others may be deemed essential to redevelopment and constructed in advance of building construction. The project team envisions the City of Somerville working with other stakeholders in the Inner Belt/Brickbottom Plan, such as property owners, to develop CFPs and CIPs and financing mechanisms.

9.1.5 Transportation system plans

Transportation system plans generally include:

- a road plan and standards for the layout of streets and their connections,
- transit stops,

- a bicycle and pedestrian plan for a network of routes within the right-of-way and through private sites,
- a parking plan,
- identification of needed transportation facilities and improvements,
- measures to encourage reduced reliance on the automobile,
- measures to minimize conflicts and facilitate connections between walking, bicycling, driving, and transit modes

These plans may call for increasing densities in new commercial office and retail developments located in designated centers. They also encompass the principle of walkability since neighborhood shopping centers may be zoned within convenient walking and cycling distance of residential areas (Oregon TGM Program, n.d.).

9.2 Market Feasibility

Market feasibility, encompassing timing and phasing and property ownership, also presents key logistical considerations for planning redevelopment. Such key considerations include working with property owners and attracting developers. Detailed analyses of these areas were largely outside the scope of this report.

The Oregon Transportation Growth Management Program has also published recommendations regarding market shaping for commercial and mixed use development. They propose both financial and regulatory development incentives.

9.2.1 Financial incentives

Redevelopment must fundamentally be profitable for developers seeking returns on investment within a timeframe. Only once developers have come forward can projects begin the permit process, such as obtaining land use approvals. Financial incentives can be used to increase the potential for profit and attract developers. Note that incentives may require a strong political endorsement of the City's role in developing the Inner Belt Core. Example incentives used by Portland, Oregon and Seattle, Washington are:

- Tax increment financing that provides funds for land acquisition and project development in targeted areas
- Tax abatements for the housing portion of a mixed-use project
- Permit fee reduction in targeted areas
- System development fee reduction/waiver in targeted areas (Oregon TGM Program, n.d.).

Reduction or dismissal of development fees can occur on a conditional basis if specified land use and design criteria are met. The City of Austin, Texas guides development in this manner (Oregon TGM Program, n.d.).

9.2.2 Regulatory Incentives

Regulatory incentives have the potential to be just as important as financial incentives if existing regulations impede plans regarding redevelopment. Various regulatory incentives include:

- Administrative review (as an option) for projects that meet the code's list of clear and objective standards for mixed-use and pedestrian orientation.
- Providing density and building height or floor area bonuses when a specified mix of uses is proposed and a high level of pedestrian orientation is provided.

- Allowing mixed-use master plans to set the development framework, followed by administrative review of specified phases of the master plan.
- Allowing “adjustments” to code standards (instead of variances) in the context of a discretionary review.
- Allowing automatic adjustment of up to a specified percentage of certain (limited) standards for mixed-use projects (e.g., building height, lot coverage, etc.) (Oregon TGM Program, n.d.).

The use of these incentives is dependent upon public dialogue regarding the local market and likely responses of developers.

9.3 Additional Infrastructural Considerations

As discussed in Section 9.1, the project team recommends capital facilities plans (CFPs) and capital improvement plans (CIPs) guide a number of up-front costs associated with construction of new infrastructure for redevelopment of the Inner Belt Core. In addition to these one-time costs, maintenance of new infrastructure is a second fiscal area of redevelopment planning.

The Community Path extension is one particular infrastructure element that requires management of maintenance and associated costs. While all roads and sidewalks within the Inner Belt Core will need snow and ice management in the winter months, snow and ice removal from the Community Path may pose unique challenges. Somerville planners have expressed concerns that if the Community Path extension to the Inner Belt Core was elevated in the air to clear the surrounding train tracks, it would be especially exposed to freezing and additionally be more costly to maintain (Hayes Morrison, project meeting at City Hall, October 13th, 2011). At this time the Community Path extension is expected to cross into the IBC from Washington St.

Station via a tunnel, eliminating the problems of an elevated structure (STEP, 2012). However, the snow and ice needs of potentially elevated pedestrian connections to adjacent neighborhoods may raise similar concerns; if this is the case, financing mechanisms for neighborhood winter operations should be considered.

10.0 Conclusions

The scope of this project involved designing an integrated urban layout in Somerville's Inner Belt Core. Specifically, this project provided a vision for a transit-oriented, walkable, mixed-use development, and created an alternative design for the Tubes. In order to create a vision outcome for the IBC, the team developed seven key principles based on *state-of-the-art design* in support of *highest and best use* for the neighborhood. An extensive literature review was conducted to develop a variety of different urban planning elements. The basis of the underpass design followed AREMA specifications and used both ASD and LFD methods. Following the design of the underpass, the group performed a cost and time estimate as well as created a plan for the construction phase.

Urban planning recommendations are founded on the seven key principles for redevelopment: economic development; mixed-use development; connectivity, walkability, and modal variety; identity and sense of place; diversity and mixed incomes; environmental sustainability; and livable community. Central vision components that realize these principles include a minimum of 30% building space as residential, thirteen intersections, bicycle storage and street accommodation, at least 15% of street frontage has a minimum building height-to-street-width ratio of 1:3, various affordable housing levels based on area mean income, LEED-certified green buildings, and a public space at least 1/6 acre in area within a 1/4-mile walk distance of 90% of dwelling units and nonresidential building entrances.

A baseline infrastructure layout map for the area implements vision outcomes. The recommended design highlights the importance of the Somerville Community Path as a critical connection to the nearest Green Line Extension station and surrounding neighborhood. The design also features an improved street network centered on a revitalized, vibrant Inner Belt Road, and a redesigned Commuter Rail Underpass allowing improved access from the north.

The Commuter Rail underpass design offers advantages over the current design through multi-modal access space. The design consists of a precast reinforced concrete deck, structural steel stringers, lateral bracing, and two semi-gravity reinforced concrete retaining walls. Through a cost estimate, the construction of the underpass is projected to cost $971,500 for the year of 2012. Assuming five normal eight-hour work days per week, the project is estimated to take seventy-one days to complete. To facilitate managing the project, the team provides proposed areas for site storage, a detour for vehicle traffic, and a way to re-route the Commuter Rail train line. Specifically, the vehicle detour will go through a fire lane located near the site, and the train will change tracks and travel through a maintenance facility located near the site.

The project team believes that this design meets the following methods set by the city of Somerville to achieve their goals of mixed-use redevelopment:

- “Mixed-use development including new housing and retail options as well as office and research;
- Enhanced transit access;
- Safe, inviting pedestrian connections within and beyond the study area;
- More convenient vehicular connections;
- Extension of the Somerville Community Path and creation of new public park space;
- Distinguished streets, parks and architecture that lend a strong new identity to this area and all of Somerville”

We envision that our transit-oriented, mixed-use design fulfills a key opportunity for economic development in the IBC with *state-of-the-art* practices.

This report summarizes potential mixed-use redevelopment practices to facilitate enhancing connectivity in Somerville's Inner Belt Core. The methods and solutions suggested in this report are preliminary and not comprehensive enough to provide conclusive guidance for redevelopment projects in the Inner Belt Core. The authors suggest that further research be completed to determine the feasibility of this report's recommendations. Specifically, next steps include researching:

- real estate market phasing & timing,
- approaches for launching a district planning board,
- future maintenance expenses for the Community Path,
- and an alternative commuter rail underpass design.

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12.0 Glossary of Acronyms

AASHTO – American Association of State Highway and Transportation Officials

ADA – Americans with Disabilities Act

AREMA – American Railway Engineering and Maintenance-of-Way Association

ASD – Allowable Stress Design

GLX – Green Line Extension

IBBB – Inner Belt/Brickbottom

IBC – Inner Belt Core

LFD – Load Factor Design

MassDOT – Massachusetts Department of Transportation

MBTA – Massachusetts Bay Transportation Authority

STEP – Somerville Transportation Equity Partnership

WPI – Worcester Polytechnic Institute

Appendix

Appendix A: Project Proposal

Transit-Oriented Redevelopment: From Light Industrial to Mixed Use in Somerville's Inner Belt Neighborhood

A Proposal for a Major Qualifying Project Report:

Submitted to the Faculty of

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

By

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Derek Andersen

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Date: October 14, 2011

Approved:

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Professor Suzanne LePage, Advisor

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Professor Leonard D. Albano, Co-Advisor

Abstract

The proposed light-rail extension of the MBTA's Green Line through Somerville, MA will influence the way residents work and live. Transportation patterns and land uses will likely change, especially in areas that currently lack rail and pedestrian transit access. This proposal outlines a process to determine appropriate transportation infrastructure changes for the Inner Belt district of Somerville. It addresses prospective pedestrian and bicycle accessibility improvements for an intended mixed-use, transit-oriented neighborhood as an approach for economic development.

Table of Contents

Capstone Design

This project will meet the requirements of the capstone design experience for a WPI Major Qualifying Project, as defined by the Accreditation Board for Engineering and Technology (ABET). ABET defines criteria that assures each engineering student is capable of attaining a certain standardized level of engineering proficiency, regardless of the school or program they attend. ABET General Criterion 3(c) states that "[each student will demonstrate] an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability." The feasibility of this project is dependent upon the application of these constraints to three major design components: the design of future transit-oriented, mixed-use redevelopment in the Inner Belt Core, the design of the Community Path as well as the street layout through the area, and the design of a new Commuter Rail Underpass at the "Tubes."

Economic

When planning redevelopment, the future market for various property uses is of primary importance for feasibility, therefore market projections and analyses will be considered. Similarly, economic factors for residents and local businesses will also be included while planning to maximize feasibility as well as economic gains. The cost and financing mechanisms of construction and maintenance of any infrastructure requirements or properties owned by the City or Commonwealth must also be accounted for. Consideration of economic constraints and opportunities is fundamentally rooted in design as a key goal of redevelopment is to increase Somerville's economic base.

Economic factors are critical in the design of the Community Path through the Inner Belt Core neighborhood. The Path is faced with significant engineering challenges due to the required clearance of multiple MBTA railway sections and construction expenses may limit feasibility. Additionally, maintenance costs of the Community Path must be managed; the City has raised concerns regarding maintenance of the Path, particularly with regard to snow and ice removal during winter months (Hayes Morrsion, project meeting at City Hall, October 13th, 2011).

The new design for the Commuter Rail Underpass will incorporate cost estimates for the design and construction phases of the project. The designs will attempt to minimize the potential economic impact on either the City of Somerville or the MBTA of MassDOT, while still meeting the appropriate design guidelines and codes.

Environmental and Sustainability

Transit-oriented redevelopment in the Inner Belt Core (IBC) has historic background in environmental considerations, as the anticipated Green Line Extension project was proposed as a solution to mitigate the region's air quality issues. Extending light-rail service from downtown Boston through Somerville and north to Medford is intended to reduce the amount of regional automobile emissions. The Somerville Community Path for pedestrian and bicycles is another important environmentally friendly aspect of the Green Line Extension.

The IBC will specifically capitalize on the transit-oriented nature of the redevelopment in order to control vehicle miles travelled (VMT) in the region, ensuring access to the proposed nearby Washington St. Station of the Green Line Extension (GLX) as well as the proposed Community Path extension. Access to the GLX station enables transit travel throughout the Boston area via the subway and bus system. The Community Path extension, a critical design consideration for this project, will in turn enhance pedestrian and bicycle travel to and from the Inner Belt/Brickbottom (IBBB) area, further reducing need for automobiles and reducing potential emissions. Additionally, redevelopment design will be planned to maximize walkability in IBC. Altogether, non-car dependent travel reduces harmful combustion pollutants that contribute to poor air quality and global warming. Focusing redevelopment in this way coordinates with the key (IBBB) development plan that the City of Somerville has developed with consultant Goody Clancy, which promotes walkable transportation options and reduced need for automobiles for regional transportation. Providing for environmentally-friendly transportation options is also needed to meet requirements outlined Somerville's Comprehensive Plan.

Political

As the project team designs potential redevelopment in the Inner Belt Core, they will consider potential political constraints to ensure the project is ultimately feasible. The project group will work closely with the Chamber of Commerce and coordinate with Somerville City Hall to ensure designs are in line with the political process and plans for the area. The final design proposal will be presented to City Hall and the Somerville's Chamber of Commerce.

Social

In addition to the Chamber of Commerce and Somerville City Hall, multiple community groups and local citizens have a vested interest in redevelopment in the Inner Belt Core. The Community Path extension, championed by local community groups such as Friends of the Path and the Somerville Transportation Equity Partnership (STEP), is a key issue in the Inner Belt area that is to be incorporated into the Green Line Extension. The project team will consider plans for the Community Path posted online by these groups, as well as reach out to them for further coordination. Additionally, the group will attend public meetings concerning redevelopment in IBBB to obtain an understanding of the public's opinions and feelings regarding the Green Line Extension and corresponding plans for redevelopment.

Ethical

The Major Qualifying Project will follow the code of ethics defined by the American Society of Civil Engineers (ASCE). The code of ethics states, "Engineers will uphold and advance the integrity, honor and dignity of the engineering profession…" (American Society of Civil Engineers, 2011). This project will provide results and designs to the proper parties involved in a professional manner. To the best of the project group's knowledge, these results and designs will be truthful, provide proper recognition to cited sources, and meet all required guidelines and codes defined by ASCE.

Health and Safety

The neighborhood's accommodations for rail, pedestrian, and bicycle access require designs that provide appropriate considerations for individual safety. Designs for the integrated Community Path, street layout, and commuter rail underpass will meet all regulations as defined by the appropriate local, state and federal laws. Designs will also address safety constraints through compliance with the Americans with Disabilities Act (ADA). Integrating the Community Path will promote healthy forms of transportation and reduce automobile emissions, supporting larger transportation goals outlined in guidelines such as GreenDOT, the Massachusetts Department of Transportation's (MassDOT) Sustainability and Livability Policy Framework.

Constructability

The constructability of the integrated urban layout is dependent upon the defined constraints, listed above. The project will provide a solution which: controls cost, mitigates impact to the surrounding environment, incorporates the needs of all involved and affected parties, meets ASCE's code of ethics, passes all state and federal laws for design, and is a sustainable investment. All of these feasibility factors combine to define the overall constructability of the project.

Introduction

Somerville is the most densely populated residential neighborhood in New England (Somerville Transportation Equity Partnership, 2011) and neighbors the scholastic institutions of Cambridge and financial core of downtown Boston. Despite the city's unique mix of metropolitan and residential lifestyle, it lacks a dedicated passenger rail service. As a result of transportation equity concerns, the Massachusetts Bay Transportation Authority's (MBTA) Green Line light-rail system will be extended through Somerville and into neighboring Medford.

The Green Line Extension (GLX) is expected to enhance the City's transportation capacity, reducing the modal share of motor vehicles and increasing the modal share of public transit, bicycling and pedestrians. Numerous outcomes are anticipated from these types of transportation changes, such as improved air quality, reduced traffic congestion, and healthier commuting practices. Additionally, recent urban planning theories have associated local economic benefits when the abovementioned modal shifts are implemented (Goody Clancy et al, 2011).

The potential for economic benefits are so high in fact, that the sponsor of this project, the Somerville Chamber of Commerce, envisions a "Green Line Extension redevelopment zone." Stephen Mackey, president and CEO of the Chamber reports that the fiscal benefits of the GLX have been recognized not only by members of the Chamber but also by MassDOT's Board of Directors, who have, "unanimously endorsed this project [the GLX] not only as a transportation project but as an economic development project" (Mackey, 2011). A majority of Somerville's associated economic benefits linked to the GLX will result from increased commercial and residential density. Areas accessible by public transport, bicycling, and walking can accommodate more compact uses, as less space is required for motor vehicle traffic and parking.

This document establishes background information and a development framework that will be used to establish a visionary plan for improving the connectivity and accessibility of pedestrian, bicyclist, and vehicular traffic in the Inner Belt Core (IBC); a sub-region of the Inner Belt district. Included in this proposal are pertinent objectives, corresponding tasks, and a project schedule necessary to accomplish the goal of this project. IBC currently lacks the appropriate layout and infrastructure to attract the mixed-use transit-oriented development that the City of Somerville and the Chamber of Commerce hopes to promote with the advent of the GLX.

Background

This section will describe the area of study, the area's transportation history, and local transportation infrastructure improvements. Understanding the future infrastructure plans within the context of local transportation history is essential to comprehending this project. The motivations for this area's redevelopment can be drawn from the community's policies for new transit opportunities. This section will also address the urban planning concepts and corresponding challenges crucial to the future of the study idea.

Area of Study

The Inner Belt and Brickbottom (IBBB) neighborhood is a light industrial area in southern Somerville. Although these areas are two separate neighborhoods, they are often coupled because of their adjacent proximity and analogous urban characteristics. This project is specifically focused on the Inner Belt Core (IBC); a sub-region of Inner Belt defined in Figure, and may occasionally refer back to distinct features of the entire Inner Belt or Brickbottom.

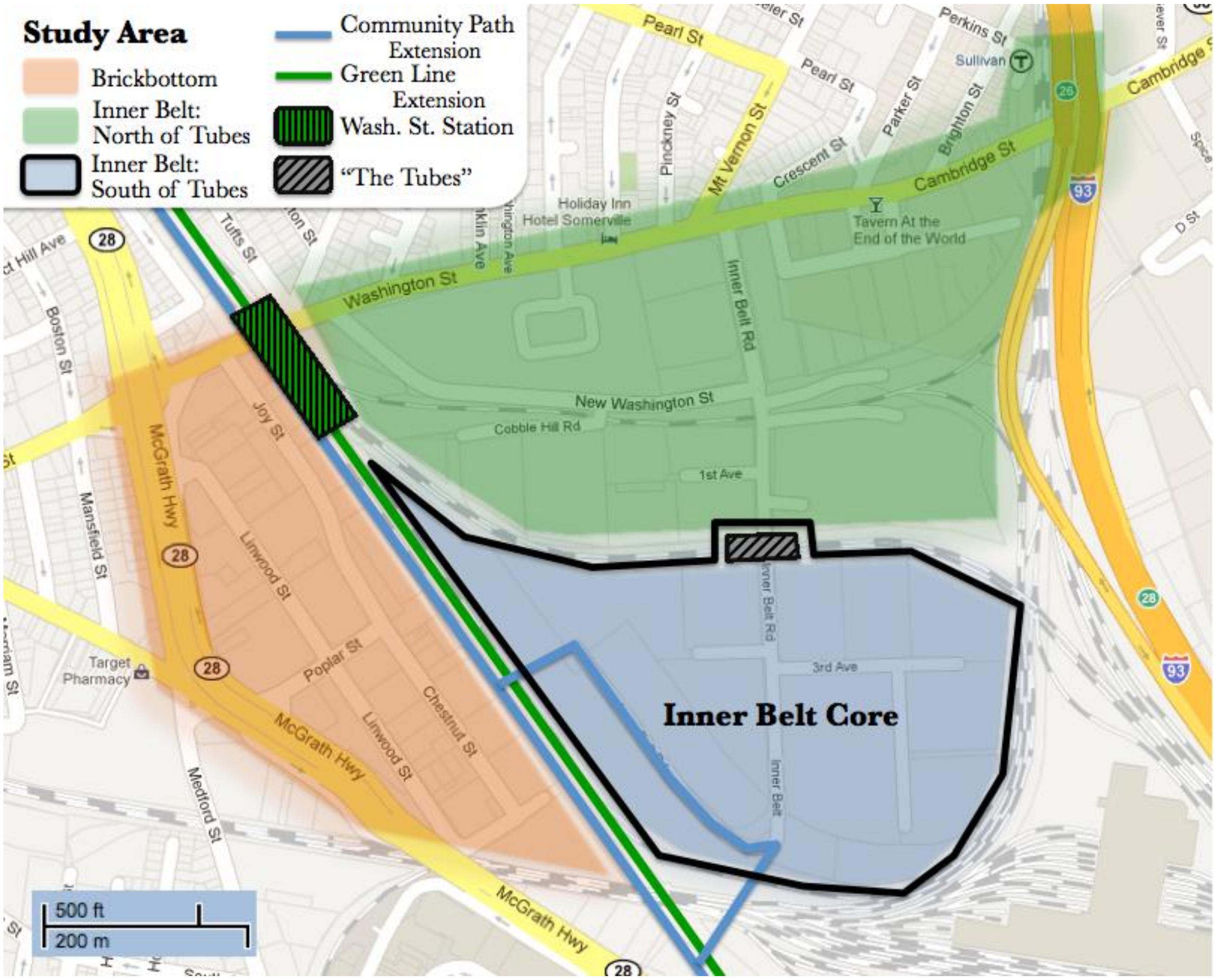

Figure 1: Study Area Map (Google Maps, 2011)

Figure depicts the IBC, which is roughly defined by existing rail lines to the east, the future Green Line Extension to the west, existing rail yards to the south, and a roadway underpass colloquially known as “the tubes” to the north (City of Somerville, 2011).The IBC contains many low-rise office parks and telecommunications hubs, as well as some manufacturing facilities. One of the MBTA’s commuter rail maintenance facilities resides in IBC. According to MassDOT, plans call for an expansion of the MBTA’s maintenance facility property in order to provide operational space for the future Green Line trains that will serve the area.

Redevelopment In the IBC: Why now?

In 1990, the MBTA's Green Line light-rail service was planned for extension as a part of a legal obligation to offset the calculated environmental impacts of Boston's Big Dig project. In 2011, project delays were announced as a result of pending applications for Federal funding and ongoing environmental impact assessments. Currently, the Massachusetts Department of Transportation (MassDOT) officials are investigating the potential to phase construction of the GLX in order to expedite its construction (Byrne, 2011). An extension of the MBTA's Green Line through Somerville is scheduled to begin construction between 2018 and 2020.

The GLX project is rooted in social, environmental, and economic equity concerns. Many Somerville residents lack viable pedestrian access to Boston's extensive commuter rail and subway system. Regardless of this, the City tolerates many of the burdens that are associated with urban transportation infrastructure. Somerville is home to the MBTA's Commuter Rail maintenance facility, a sizable property and operation that cannot be taxed. Eight passenger rail lines extend through Somerville despite Davis Station operating as the only MBTA subway station located within Somerville's city limits (Somerville Transportation Equity Partnership, 2011).

Somerville not only lacks substantial passenger rail access while hosting an MBTA maintenance facility, but The City also retains many major highways. Interstate-93 and Massachusetts Route-28 (McGrath Highway) are essential roadways for many regional and local automobile users. However, the automobiles that often congest these roadways degrade Somerville's air quality (Somerville Transportation Equity Partnership, 2011). Additionally, the rate of traffic and elevated design of these roads disrupt Somerville's urban layout and are barriers to neighborhood connectivity and economic development. Many of Somerville's residents, community groups, businesses, and politicians identify the GLX as a strategic transportation resource that provides ample opportunity for economic development.

Another future transportation resource expected to impact Somerville is the improvement of an existing bike and pedestrian path called "the Community Path." Constructed on a former railroad right-of-way, the Community Path was built to reduce automobile trips, promote alternative commuting practices, and encourage recreation. This pedestrian and bicyclist right-of-way is available to users in northwestern Somerville near Davis Square and extends west into neighboring Medford. The eastern terminus currently lies at Cedar St. in Somerville. To complement the GLX's local transportation improvements, an extension of the Community Path from Cedar St. is being planned by MassDOT. Both the GLX and the Community Path will run parallel to each other through southern Somerville.

Both the Green Line Extension and the Community Path extension are vital undertakings relevant to IBC's redevelopment. The GLX's proposed Washington St. Station is within walking radius to most locations in the IBC, making the area a viable option for transit-oriented development. To complement the district's redevelopment potential, the Community Path extension will enhance the IBC's pedestrian and bicycle connectivity. Depictions of the GLX, the Community Path extension, and their related proximities to the IBC are available in Figure.

IBC's Future Vision

With municipal, commercial, and residential support, land uses in the Inner Belt Core

(IBC) can evolve to fully seize the opportunities of a new transportation resource. The City of Somerville and Chamber of Commerce envision the residing light industrial and low-density layout of the larger Inner Belt/Brickbottom area transforming into a transit-oriented, mixed-use development district.

The Inner Belt/Brickbottom Plan is a key collaboration of vision for the area led by the City that draws upon "residents, City staff, businesses, organizations, institutions, and other stakeholders working together." Its vision is to:

- Create a new mixed-use Somerville neighborhood of choice.
- A place that attracts skilled and educated workers, and therefore significant

  investment
- An amenity and source of economic opportunity for Somerville and the region (Goody Clancy et al., 2011).

Challenges associated with this vision are market competition with other sites; access and circulation infrastructure; planning and urban design to create walkability and enhance the area's Somerville character; significant phasing and financing implementation challenges; and developing and sustaining political will, understanding, and support (Goody Clancy et al., 2011). Plans for redevelopment must address these challenges for success.

The emerging plan will capture the unrealized potential of Inner Belt and Brickbottom by making them new regional focal points of economic activity and quality sense of place. Strategic urban planning is needed to transform the area from a light industrial park into a mixed-use development community. Determining the optimal mixed-use development strategy in order to increase economic potential and create a sense of place is an important consideration for this project, as dense centers of commerce and civil interaction have been associated with numerous environmental, economic, and social advantages. Planning the transition of this area through zoning strategies and market incentives is crucial for such a desired transformation. Corresponding design considerations include walkability, proximity to storefronts, and landscape architecture.

Stakeholders

The future of IBBB will depend on a range of voices, decisions, and actions executed on behalf of various organizations. These organizations are interconnected and play significant roles pertaining to this project. Figure 2 illustrates the categories and relationships these organizations retain.

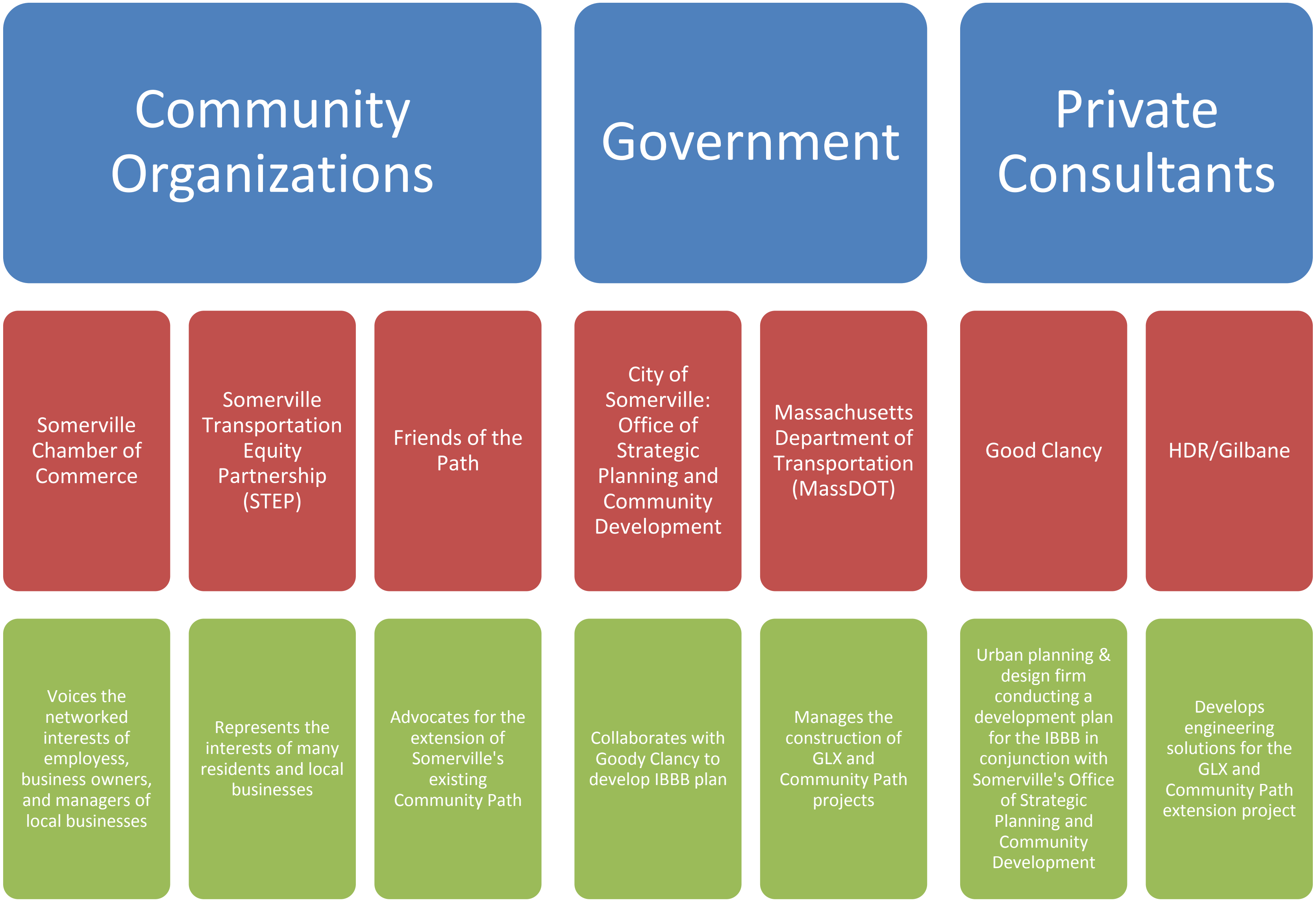

Figure 2: Key Organizations

Development Challenges: Limited Connectivity

Limited connectivity is a large barrier to economic opportunities of redevelopment in the Inner Belt Core. Additional access points are likely key to increasing the economic viability of development in the Inner Belt. The area is essentially an island, with only one public point of vehicular and pedestrian access, underneath the commuter rail underpass known locally as the "Tubes." Since Inner Belt Road is not a throughway, people only enter the area if it is their destination. While the Green Line Extension's proposed Washington St. station is expected to generate an additional flow of people near the Inner Belt/Brickbottom area, travelers leaving the station will not necessarily enter the Inner Belt Core.

Community Path

Connecting to the proposed Community Path through the GLX Washington St. Station is an opportunity to bring more pedestrian traffic into the Inner Belt, boosting the customer base of potential businesses. MassDOT plans to incorporate an extension of Somerville's Community Path into the Green Line Extension. Such an extension would link the Minuteman Bikeway/Linear Park (the most-used rail trail in the USA) to the Charles River Paths (Friends of the Path, 2011). Not only would an extension of the Community Path through the area increase the amount of people travelling through the area, it would also provide a key second point of access directly connected to a Green Line Extension station, facilitating transit-oriented development.

Limited Access at "the Tubes"

Inner Belt Road is currently the only access point into and out of the IBC. During the late 1970's a team of engineers constructed a railway underpass, known as "the Tubes", over Inner Belt Rd to accommodate the Lowell commuter rail line. The Tubes provide access into and out of the Inner Belt Core and connect the Lowell commuter rail line between the West Medford station and North Station. At the time, the engineers designed the tubes to be a temporary structure; however, they remain today (Mackey, 2011). Although the tubes facilitate traffic into the IBC, they pose a few problems.

Figure 3 below shows the oval design of the tubes. The tubes create a tight clearance for vehicles and reduce sidewalk capacity to a lane approximately one pedestrian wide. The clearance restricts certain vehicles from entering the industrial park and in the past, vehicles have struck and damaged the Tubes. In the past large trucks have even become lodged in the Tubes. The narrow sidewalks restrict pedestrian flow and pose potential danger to pedestrians due to the close proximity of traveling vehicles through the Tubes (Mackey, 2011). Additionally, the dimensions prevent bikes from sharing the road with vehicles. In 2011, a report for the Somerville police indicated a documented bike crash occurred at the tubes in 2010 (Reported Bike Crashes, 2011). Although the Tubes permit most vehicles, they cannot accommodate simultaneous modal uses.

Figure 3: The Tubes (Crocker, 2011)

Possible Vehicular Connectivity from IBC to Brickbottom and East Cambridge

Due to the limited connectivity in the IBC and the potential increase traffic flow around the Inner Belt area, the city of Somerville would like to increase connectivity to IBC. The city would like to connect the IBC with Brickbottom using a bridge as part of redevelopment. Additionally, the city would like to construct a bridge over the rail yard and connect to East Cambridge (B. Carlson, public meeting, October 5, 2011). Due to the engineering challenges and economic constraints presented by both of these proposed bridges, especially the East Cambridge bridge, these designs will be integrated into the later phases of the City's plan.

Summary

The aforementioned background sections identify challenges to redevelopment within the context of local transportation history and contemporary concepts for IBC's redevelopment. Specifically, these challenges are the integration of the community path into the IBC and the access issues produced by the Tubes. With the identified issues, the project team will establish a goal and scope the supporting objectives needed to develop a vision for the IBC.

Goal

The goal of this project is to design an integrated urban layout along Somerville's Inner Belt Community Path, increasing connectivity to the MBTA's proposed Washington Street Station and the surrounding area as an initial step for redevelopment of the Inner Belt. Specifically, design a vision for a walkable, mixed-use development that fulfills the Inner Belt/Brickbottom Plan's vision of a regional focal point of economic activity with a quality sense of place. This design will improve access issues currently posed by the commuter rail underpass ("the Tubes") and promote increased pedestrian and cyclist traffic through the area according to the principles of social, economic, and environmental sustainability.

Scope of Work

Developing the scope of work for this project involved site visits, participating in meetings, and identifying the major steps towards redevelopment of the Inner Belt Core (IBC). The infrastructure development opportunities this project will address are the issues of accessibility and connectivity, specifically relating to the proposed Community Path and the Tubes. Based on these identified problems, the team has identified six objectives as key to implementation of the Goal. The six objectives of this project are:

1) Redevelopment: Design a vision for transit-oriented, mixed-use development

2) Redevelopment: Plan the transition from light industrial to mixed-use

3) Access: Integrate the Community Path and a mixed-use street grid

4) Access: Analyze the traffic outcomes of various modes

5) Redesign the Tubes: Develop a commuter rail underpass design

6) Redesign the Tubes: Propose project management techniques for underpass construction

The first two objectives are proposing a vision and transition plan for redevelopment of the IBC. Specifically the first objective will deliver a mixed-use vision. This task entails researching modern urban planning theory in addition to case studies, and applying this to the area of interest. The second objective will offer a transition plan for the vision. The transition plan will involve zoning the area and defining the proportion of mixed-use development in the area. This objective will correlate to the first objective and assist in defining and planning mixed-use development for the IBC.

While redeveloping the IBC it is essential to integrate the Community Path into the street grid and envision potential flow into the area from the Community Path. The third objective is to integrate the Community Path into the street grid. This will involve designing the path to comply with the Americans with Disabilities Act (ADA). The fourth objective is to envision potential flow into the area from the Community Path and predict how it will affect the area. This will involve three phases: researching case studies and methods, determining projected pedestrian traffic, and predicting the corresponding economic impact. These two objectives will address pedestrian and bicyclist accessibility and connectivity issues.

In order to improve mixed-use access into the IBC, the fifth Objective will provide a design for an alternative commuter rail underpass to replace the Tubes. The design will incorporate additional space for larger vehicles, bicycles, and pedestrians on Inner Belt Road. This objective will involve researching appropriate guidelines, specific railroad bridge designs, and applying these two research fields to develop an appropriate design. The sixth objective will provide recommendations for project management techniques that will mitigate the effect on the IBC and the Commuter Rail. In addition to the recommendations, this objective will also provide cost and time estimates for constructing the Commuter Rail Underpass specified in the fourth objective.

Methodology

This section will discuss plans to achieve each of the six abovementioned objectives. Figure below shows the timeline for the project. Each objective is assigned to a specific timeline with respect to this project's critical path, as a identified with a red letter "C."

					B -	Term				Break				C -	Term			
		24-Oct*	31-Oct.	7-Nov.	14-Nov.	21-Nov*	28-Nov.	5-Dec.	12-Dec*		9-Jan*	16-Jan*	23-Jan.	30-Jan.	6-Feb.	13-Feb*	20-Feb.	27-Feb.
Project Objectives																		
1st Objective		C	C					C	C									
2nd Objective																		
3rd Objective				C	C													
4th Objective						C	C											
5th Objective																		
6th Objective																		
Writing the Project																		
Background																		
Methodology											C	C						
Results													C	C				
Conclusion															C			
Introduction																		
Executive Summary																C		
Abstract																		
Final Edits																	C	C
MakePresentation																		
KEY																		
Research																		
Design																		
Design Editing																		
Writing/Editing																		
Critical Path	C																	
* Means that this is not a full academic week																		

Figure 4: Timeline For MQP

Coordination with Somerville Stakeholders

To ensure our design is the most beneficial and appropriate for Somerville, this redevelopment will coordinate with the stakeholders identified in the Background and outlined in Figure 2. It will further the goals of the Chamber of Commerce, coordinate with existing plans for the area, integrate with the City of Somerville's larger plans, and consider the values and needs of Somerville's residents.

The project team has been and will continue to take a number of different steps to coordinate with the City. With a recommendation from a Chamber of Commerce representative, the team is identifying and contacting representatives of various Somerville organizations and departments to discuss the proposed redevelopment and take note of existing plans, concerns, and ideas for the area. The groups to which the team has reached out to include the Somerville Office of Strategic Planning and Community Development, Somerville Transportation Equity Partnership, Friends of the Path, and Goody Clancy's Inner Belt/Brickbottom (IBBB) team.

Furthermore, the team participated in a number of on-site meetings in Somerville, which developed an understanding of IBBB. The team began scoping the project by arranging an informational site visit of IBBB with Chamber of Commerce representative, Stephen Mackey. The visit provided a sense of the area's walkability, existing property uses, IBBB businesses, Green Line Extension maintenance facility details, and anecdotal information regarding the Tubes. Mackey spoke about the Chamber's vision for redevelopment in the area in conjunction with the planned Green Line Extension transit system. Additionally, Mackey introduced the team to various studies and potential plans for the area that should be taken into consideration. Altogether, the site visit was instrumental in providing direction for the focus of the project.

The project team is planning to attend various relevant redevelopment meetings in order to integrate this project's direction with existing planning efforts. The information gathered from these meetings will provide a foundation for this project's design. Once the project team establishes a project foundation, the project team must move forward with its own design with respect to time constraints.

Such key meetings that the team has already attended include the Green Line Extension (GLX) Community Path meeting and the second public meeting of the Inner Belt/Brickbottom Plan. The GLX Community Path meeting presented the team with the latest proposed designs and directions of the path, as well as provided various key considerations for urban planning in conjunction with the path. At the IBBB Plan public meeting the team learned about the City of Somerville's development ideas for IBBB, the Goody Clancy team's projected market analysis, and participated in the IBBB visioning sessions. Future relevant Somerville meetings to further inform the foundation for this project's design.

Redevelopment: Design a vision for transit-oriented, mixed-use development

Through research of transit-oriented, mixed-use redevelopment theory and practice, in addition to coordination with existing Somerville visions for the area, the project team will propose a design of the types and distribution of future land/ property uses of development in the Inner Belt Core.

The team will draw inspiration for redevelopment from key visioning in the Inner Belt/Brickbottom Plan previously mentioned and discussed in the Background. Also key in planning will be designing in accordance with the Somerville Comprehensive Plan of the Office of Strategic Planning and Community Development (OSPCD), which offers guidelines for planning and creating future development opportunities. The team will incorporate ideas from other Somerville groups. When designing redevelopment, the project team will research and consider previous proposal and studies of the area. Such resources include "Inner Belt/

Brickbottom: Scoping Study," a study commissioned by the City of Somerville to envision redeveloped in the area with the anticipated Green Line Extension. Another resource is "Edge As Center: Envisioning the Post-Industrial Landscape," a collection of visions for the Inner Belt/ Brickbottom area generated from an urban design ideas competition organized by OSPCD in partnership with the Boston Society of Architects.

Research into redevelopment theory and practice will be the chief method for fulfilling this objective. The research will involve overall trends of redevelopment and mixed-use, transit-oriented development, as well as research the projected land use market demands for housing, businesses, and research facilities. Examination of relevant case studies will be useful for assessing successes, failures, and different outcomes.

Through this research, principles of redevelopment and a range of redevelopment evaluation criteria will be identified. A small number of alternatives for redevelopment in the Inner Belt Core, displayed through maps and street profiles, will then be developed as final deliverables. These alternatives will be accompanied by corresponding explanation of the mixed-use development chosen and supporting rationale, and each alternative would be evaluated in terms of the criteria developed.

Redevelopment: Plan the transition from light industrial to mixed-use

In this second redevelopment objective, the transition to achieve the redevelopment envisioned in the previous section is outlined. Redevelopment can be planned through strategic zoning and a variety of different incentives. As for the first step of establishing a vision for the Inner Belt, it is again important to coordinate with Somerville planning efforts regarding the transition of property uses. The project team will contact City officials in order to obtain Somerville's

Comprehensive Plan and work in conjunction with appropriate zoning. In addition to coordinating with existing plans for transitioning the area, the project team will again research redevelopment theory and practice and examine applicable case studies. By investigating what practices have worked in the past to create similar mixed-use development communities, as well as by studying which practices did not achieve desired outcomes, the project team will develop a proposal for transition strategies.

Access: Integrate Community Path and a mixed-use street grid

Envisioning the potential flow into the IBC from the community path and the projected impact involves two main steps. The first is predicting pedestrian and cyclist flows into the area. This aspect of the project involves researching existing data on current and projected path traffic and determining how to predict traffic flow into the area. The second step will offer a vision of economic benefit to the area from the community path traffic. This requires researching similar case studies and theory on economic benefit from increased pedestrian and cyclist traffic. These two steps will provide a basis for predicting the economic impact due to increased pedestrian flow.

Access: Analyze the traffic outcomes of various modes

After calculating potential traffic flows, determining design aspects of the Community Path and how it will interact with the rest of the IBC's roads is an important next step in this project. Distinguishing desirable path criteria and illustrating the findings of this project will communicate to the sponsor how the path could cooperate with the IBC's proposed mixed-use development.

Research Desirable Path Criteria

The Community Path must maintain a functional, safe, and appealing characteristic. This project will examine methods to assimilate the Community Path into a "complete street" design that will provide adequate road space for bicycling, pedestrians, and motor vehicles. Safety designs will be drawn from MassDOT's catalogue of transportation planning guidelines. Landscape architecture will also be examined to promote aesthetic attraction for pedestrian and cyclist traffic. These uniting design factors will make the Community Path extension through IBC a permeable artery, encouraging pedestrian and bicycle traffic to exit the path and explore the IBC.

Integrate Community Path Design into the Project using AutoCAD

To demonstrate the design of this project, it will be necessary to utilize AutoCAD. Project members unfamiliar with the digital illustrating program will find it necessary to research online teaching resources and perhaps use appropriate manuals and textbooks. Once acquainted with the software, the latest Community Path designs will be obtained from MassDOT and incorporated with the aforementioned design aspects to provide a suite of visual illustrations.

Redesign the Tubes: Develop a commuter rail underpass design

In order to provide easier access to the Inner Belt area the project team will propose a new design for a Commuter Rail underpass bridge to replace the Tubes. The design will accommodate a higher elevation clearance, a bike lane, and an increased sidewalk width to allow better multi-modal travel through the underpass. The Massachusetts Department of Transportation (MassDOT) defines the criteria for appropriate road, bike lane, and sidewalk width. The bridge design will require research into appropriate railway bridge designs that incorporate the existing site conditions. Once this step is complete, the team will design a railway bridge, which meets the design guidelines as specified by the American Railway Engineering and Maintenance-of-way Association (AREMA).

Redesign the Tubes: Propose project management techniques for underpass construction

The Tubes serve as an access point into and out of the Inner Belt Core, and provide transportation for the Lowell Commuter Rail line between the West Medford station and North Station. In order to mitigate the impact on the commuter rail line and traffic, the project team will research and propose project management methods to allow for a cost and time efficient project. These methods will: provide cost and time estimates for constructing the project, facilitate traffic into and out of the Inner Belt Core during construction, and accommodate transportation for the Lowell Commuter Rail passengers.

Summary

The Methodology is the process the team will implement to meet the goal of developing a vision for the city of Somerville. Redeveloping the Inner Belt Core will require addressing the issues of accessibility and connectivity in conjunction with a future vision. We will implement the proposed methods and produce a detailed vision for the IBC.

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Appendix B: Select LEED-ND Guideline Details

Table B-1: LEED-ND Transit Service Minimums

	Weekday trips	Weekend trips
Projects with multiple transit types (bus, streetcar, rail, or ferry)	60	40
Projects with commuter rail or ferry service only	24	6

Table B-2: LEED-ND Diverse Uses to Connect by Bicycle Network

Food Retail

Supermarket
Other food store with produce

Community-Serving Retail

Clothing store or department store selling clothes
Convenience store
Farmer's market
Hardware store
Pharmacy
Other retail

Services

Bank
Gym, health club, exercise studio
Hair care
Laundry, dry cleaner
Restaurant, café, diner (excluding establishments with only drive-throughs)

Civic and Community Facilities

Adult or senior care (licensed)
Child care (licensed)
Community or recreation center
Cultural arts facility (museum, performing arts)
Educational facility (including K–12 school, university, adult education center, vocational school, community college)
Family entertainment venue (theater, sports)
Government office that serves public on-site
Place of worship
Medical clinic or office that treats patients
Police or fire station
Post office
Public library
Public park
Social services center

Table B-3: LEED-ND Affordable Housing Guidelines

Rental dwelling units				For-sale dwelling units			
Priced up to 60% AMI		Priced up to 80% AMI		Priced up to 100% AMI		Priced up to 120% AMI	
Percentage of total rental units	**Points**	Percentage of total rental units	**Points**	Percentage of total for-sale units	**Points**	Percentage of total for-sale units	**Points**
5	**1**	10	**1**	5	**1**	8	**1**
10	**2**	15	**2**	10	**2**	12	**2**
15	**3**	25	**3**	15	**3**	--	**--**
AMI = area median income.							

Sub-Appendix B-4: LEED-ND Green Building Certification Options

LEED for New Construction, LEED for Existing Buildings: Operations & Maintenance, LEED for Homes, LEED for Schools, LEED for Retail: New Construction, or LEED for Core and Shell (with at least 75% of the floor area certified under LEED for Commercial Interiors or LEED for Retail: Commercial Interiors), or through a green building rating system requiring review by independent, impartial, third-party certifying bodies that have either been accredited by an IAF accreditation body to, or could demonstrate compliance to, ISO 17021 or ISO/IEC Guide 65, and, when subsequently available, ISO/IEC 17065.

Appendix C: Commuter Rail Underpass Supporting Calculations

C-1: Superstructure & Substructure Design (Except for HCB & Overturning Moment Design for the Substructure)

(1.1) Notations

A = Area
A_g = Gross Area of Section
A_s = Area of Reinforcing Steel
a = Depth of Equivalent Rectangular Stress Block
B = Buoyancy
b = Base width
CF = Centrifugal Force
c = Distance from Extreme Compression Fiber to the Neutral Axis
D = Dead Load
d_b = Diameter of bar
d_e = Effective Depth
E = Earth Pressure
EQ = Earthquake Loading
F = Longitudinal Force due to Friction
*F_F = Force due to Friction
F_i = Force
F_R = Reaction Force
FS = Factor of Safety
F_y = Force in the Y-Direction
F_{ye} = Yield Strength of Steel Bar
f_y = Yield Strength of Steel
h = Thickness of Slab
h' = Effective Height of Earth due to Surcharge
h_1 = Height of Earth Behind Retaining wall
I = Rotational Moment of Inertia in either x-x or y-y direction, noted by I_x or I_y
ICE = Ice Pressure
$I.L.$ = Impact Load
KSI = Kips per Square inch
k = Kips
L = Live Load
LF = Longitudinal Force from live load
L_i = L_m = Length of Member
M = Bending Moment
M_n = Maximum Moment due to Negative Flexure
M_p = Maximum Moment due to Positive Flexure
M_u = Maximum Moment Applied to Retaining wall
OF = Other Forces
P = Earth Pressure
P_i = Pressure
psi = Pounds per Square inch
R_n = Flexural Resistance Factor
*r_x = Radius of Gyration
S_e = Effective Span Width
SF = Stream Flow Pressure

(2)

Notations (Continued)

S = Elastic Section Modulus (S_x = S in the x-x Direction)
T = Thickness
V_c = Cracking Shear Force
V_u = Total Shear Force Applied to a Section
W = Wind Load on Structure
WL = Wind Load on Train
W_x = Weight of a Sub-section of the wall (x = number)
Y = Location of Earth Pressure above the Footing
α = Coefficient of Thermal Expansion
β = Ratio Reduction Factor
γ = Density of Material/Earth
γ_s = Angle of Deflection due to Shear
Δ_{DL} = Deflection due to Dead Load
ΔL = Change in Length
Δ_{LL} = Deflection due to Live & Impact Loading
Δ_{max} = Maximum Deflection
ΔT = Change in Temperature
Δ_T = Total Mid Span Deflection
ϵ_T = Net Tensile Strain of the Reinforcement
ϵ_u = Concrete Compressive Strain Limit
θ_{DL} = Angle of Deflection due to Dead Load
θ_{LL} = Angle of Deflection due to Live & Impact Load
θ_T = Total Angle of Deflection
* λ = Modification Factor for Light Weight Concrete
ρ = Reinforcement Ratio
σ = Bending Stress
σ_{ac} = Actual Stress
σ_{all} = Allowable Stres
ϕ = Strength Reduction Factor
' = Feet
'' = Inches

* - Additional Notation

f'_c = Concrete Compressive Strength
$\sin\phi$ = Sin of the Cohesion Angle of Internal Friction
l_{dh} = Development Length of the Hook in Tension

The approaches, equations, and estimates for the design were based primarily on the AREMA Manual. For equations and values not commonly commonly used, a citation will be provided in the same Format as the paper. The citations are provided in the Bibliography.

(3)

1.2 Superstructure:

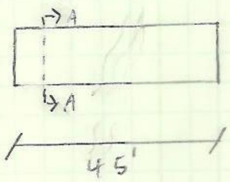
(1.2.1) Design Loads: Superstructure

(a) Dead Loads:

- Track Rails, inside guard rails, & fastenings
  = 0.200 kips/ft × 45.0 ft = 9.00 kips

- Ballast & track ties
  = .120 kips/ft³ × 45.0 ft × 36 ft × 1 7/12 ft = 308 kips

- Precast Concrete Deck Estimate



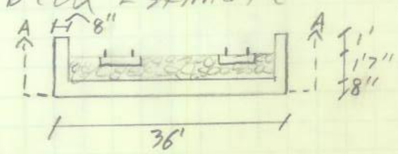


Figure : Side view   Figure : Cross section A-A

= .150 kips/ft³ × [45.0 ft × (8/12) ft × 36 ft + 45.0 ft × (8/12) ft × 2 7/12 ft] = 195 kips

- Steel Beams (Assume 6 beams with .168 kips/ft)
  = .168 kips/ft·beam × 6 beams × 45 ft = 45.4 kips

Total Dead Load = D = 557 kips

(b) Live Loads (Two Cooper E80 trains moving in opposite directions

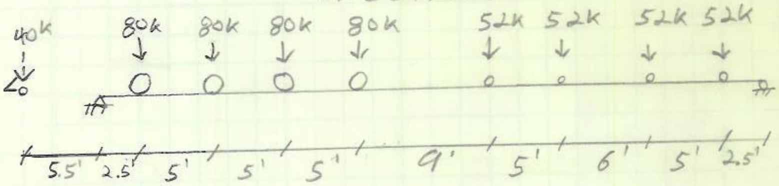


Figure 1st train

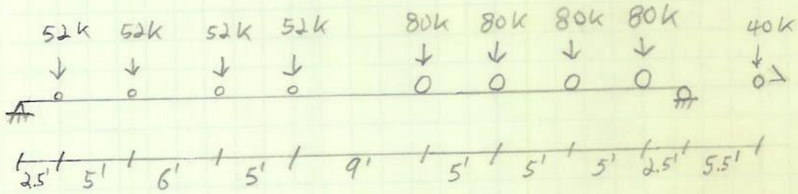
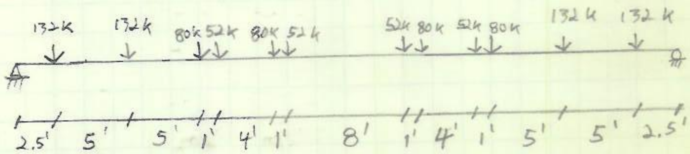


Figure 2nd train

(4)

1.2.1

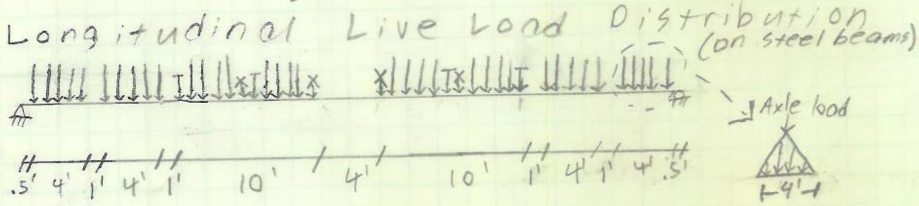
- Combined Live Load



LL = 1056 k

Figure 3

- Longitudinal Live Load Distribution (on steel beams)

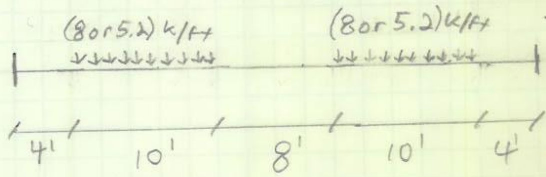


key: ↓ = 33 k/ft I = 20 k/ft ↕ = 13 k/ft

(Axle load distributed over 3 feet plus the ballast depth between axles)

Figure 4

- Lateral Live Load Distribution per Axle



→ Assum 8 k/ft since it is a larger value

Figure 5

(C) Impact Loads

I - vertical Effects

$$\text{Loading} = \text{Live Load} \times \left(40 - \frac{3 \times 45^2}{1600}\right)/100$$

$= L \times 0.362$ (Applied to figure 3)

- Rocking Effect

(Next Page)

1.2.1 ⑤

- Lateral Rocking Effect (per Axle)

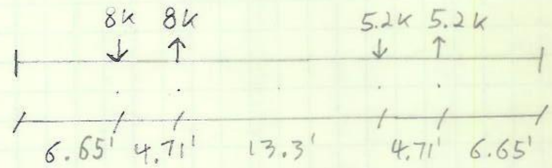


Figure 6

* For Impact Load to Ballasted Deck take 90% of the above calculated Loading * (AREMA, 2010b)

C_F ⓓ Centrifugal Force

$F_c = 0$

E ⓔ Earth Pressure forces applied to super structure

$E = 0$

B ⓕ Buoyancy

$B = 0$

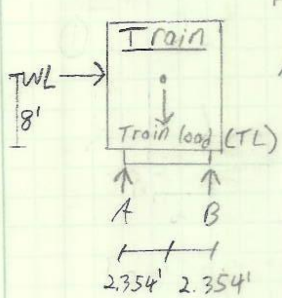
W ⓖ Wind Load on Superstructure (Applied at the center of gravity, perpendicular to the tracks)

$W = .045 \frac{k}{Ft^2} \times 45' \times 3.42' = 6.93\ k$ (AREMA, 2010b)

WL ⓗ Wind Load on Live Load (Applied 8' above the top of the rail, perpendicular to the tracks)

$WL = .300 \frac{k}{Ft} \times 45' = 13.54$ (AREMA, 2010b) $TL = 52k \cdot 4 + 80k \cdot 4$

$TL = 528k$



A & B = Rail supports

$\Sigma M_A = 0 = WL \times 8' + TL \cdot 2.35' - B_y \cdot 4.708'$

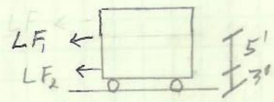
$B_y = 287\ k$

$\Sigma F_y = 0 \quad \therefore A_y = 241\ k$

1.2.1 (6)

LF ① Longitudinal Load

- Load due to braking(LF_1) & Load due to traction(LF_2)



$LF_1 = 45 + 1.2 \cdot 45' = 99\ k$

$LF_2 = 25\sqrt{45'} = 168\ k$

(AREMA, 2010b)

~~For superstructure: L_{F_1} = 49.5 k, L_{F_2} = 84.0k~~

EQ ⓙ Earthquake Load:

After initial calculations it was determined an analysis wasn't necessary due to the structure's size and geometry (AREMA, 2010 a)

OF ⓚ Snow Load & Rain Load

$.04 \frac{k}{ft^2} \times 36' \times 45' = 64.8\ k$ & $.0624 \frac{k}{ft^3} \times .5' \times 36' \times 45' = 50.5k$

OF = 64.8k & 50.5k. (Somerville, 2011)

Since snow load is larger, 64.8k will be used

SF ⓛ Stream Flow Pressure

not present for superstructure

1.2.1-

Loading Combination (Load Factor Design): Reinforced Concrete Deck

- **Group I**

$1.4(D + \frac{5}{3}(L+IL) + \cancelto{0}{CF} + \cancelto{0}{E} + \cancelto{0}{B} + \cancelto{0}{SF})$

$1.4(557 + \frac{5}{3}(1056(1+.362\times.9))) = \boxed{4047\ K}$ ↳ Governs Design

- Group IA

$1.8(D + L+IL+ \cancelto{0}{CF} + \cancelto{0}{E} + \cancelto{0}{B} + \cancelto{0}{SF})$

$1.8(557 + (1056(1+.362\times.9))) = 3510\ k$

- Group II

$1.4(D+\cancelto{0}{E}+\cancelto{0}{B}+\cancelto{0}{SF}+W) = 1.4(550 + 6.93) = 780\ k$

- Group III

$1.4(D+L+IL+\cancelto{0}{CF}+\cancelto{0}{E}+\cancelto{0}{B}+\cancelto{0}{B}+\cancelto{0}{SF}+0.5W+WL+LF+\cancelto{0}{R})$

$1.4(550+1056\times1.3258+\frac{6.93}{2}+13.5+168) = 2955\ k$

- Group IV

$1.4(D+L+IL+\cancelto{0}{CF}+\cancelto{0}{E}+\cancelto{0}{B}+\cancelto{0}{SF}+OF)$

$1.4(550+1056\times1.3258+64.8) = 2830\ k$

- Group V

Group II $+ 1.4(OF) = 780+1.4\times64.8 = 871\ k$

- Group VI

Group III $+ 1.4(OF)$

$2955+1.4\times64.8 = 3046\ k$

- Group VII

$1.4(D+\cancelto{0}{E}+\cancelto{0}{B}+\cancelto{0}{SF}+\cancelto{0}{EQ}) = 1.4(550) = 770\ k$

- Group VIII & Group IX

8: $1.4(D+L+IL+\cancelto{0}{E}+\cancelto{0}{B}+\cancelto{0}{SF}+\cancelto{0}{ICE}) = 2730\ k$

9: $1.2(D+\cancelto{0}{E}+\cancelto{0}{B}+\cancelto{0}{SF}+\cancelto{0}{W}+\cancelto{0}{ICE}) = 660\ k$

1.2.2 Superstructure: Steel Stringer Design ⑧

1.2.2.1 Shear & Moment Diagrams: Superstructure (Longitudinal)

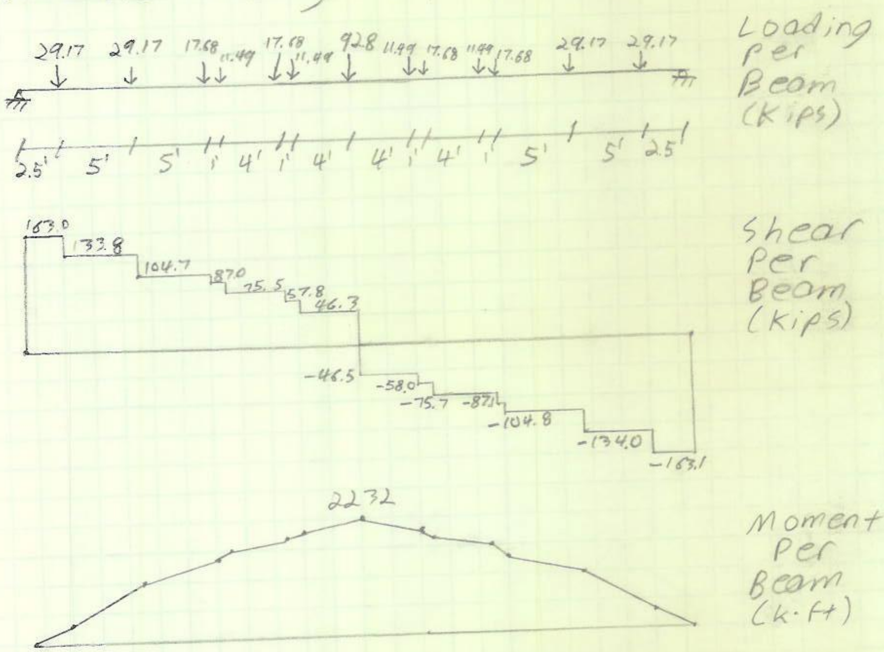
LFD will be used for the reinforced concrete Deck. ASD will be used for the steel stringer Design, due to the AREMA steel guidelines not having LFD available.

According to AREMA guidelines and initial calculations Dead, Live, and impact loads will govern design of the steel stringers:

$D + L + IL = 1957\text{k}$

Equivalent load per beam $= 1957 / 6\text{ beams} = 326\text{k}$

Symmetric loading $\therefore A_Y = B_Y = 163\text{ k}$



1.2.2 (9)

1.2.2.2 Structural Steel Stringers

$F_y = 70$ ksi (A709, Grade HPS 70W)

- Bending stress: $\sigma = \frac{Mc}{I} \rightarrow S = \frac{I}{c} = \frac{M}{\sigma}$

$S = \frac{M}{\sigma} = \frac{(2232 \times 12)}{(.55 \times 70)} = 696 \text{ in}^3$

*6 Beams are not efficient enough, S is too large

8 beams → new $M = 2232 \text{ k·ft} \times \frac{6 \text{ beams}}{8 \text{ beams}} = 1674 \text{ k·ft}$

$S = \frac{M}{\sigma \cdot FS} = \frac{(1674 \times 12)}{(.55 \times 70)} = 522 \text{ in}^3$

Select a W 30 x 173 ($S_x = 539 \text{ in}^3$)

Correct dead load

$.173 \frac{\text{kips}}{\text{ft·beam}} \times 8 \text{ beams} \times 45 \text{ ft} = 62.28 \text{ k}$

∴ corrected dead load = 62.28 (increase by 16.88 k)

Correction to moment: $\frac{16.88 \text{k}}{8 \text{ beams}} = 2.11$ k shear increase per beam

Moment $= 1674 + 2.11 \text{k} \times 22.5' = 1721 \text{ k·ft}$

$S = \frac{M}{\sigma \times S} = \frac{(1721 \times 12)}{(.55 \times 70)} = 536 \text{ in}^3 \leq 539 \text{ in}^3$ ✓

Properties of W30 x 173 ($S_x = 539 \text{ in}^3$)

A (in²)	depth (in)	width (in)
50.8	30.44	14.985

Strong axis:

I_x (in⁴)	r_x (in)
8200	12.7

- Compression in extreme fibers of I-beam

Same values as above.

1.2.2 (10)

(steel stringers)

• Axial compression

$F = 168\,k \times 2\text{ trains}/8\text{ beams} = 42\,k$

$\sigma_{all} \geq \sigma_{AC} \rightarrow .55 \times 70\text{ ksi} \geq \frac{42k}{50.8''} \Rightarrow 38.5 \geq .827$ ✓

• Slenderness ratio

$\frac{L_m}{r_x} \leq 100 \rightarrow \frac{45'}{(12.7''/12\text{ in/ft})} = 42.5 \leq 100$ ✓

• Deflection of Beam

Allowable Deflection = 45'/640 = .0703' = .844''
(due to live & impact loading, not dead load)

Loading assumptions: distributed load = 2.59 k/in

$\Delta_{max} = \frac{5 \times .324 \times (45 \times 12)^4}{384 \times 29000 \times 8200} = 1.51'' \nleq .844''$ N.G.

New beam: W30x292 (AISC, 2011)

Properties: $A = 86.0\text{ in}^2$ $d = 32.0''$ $I_x = 14{,}900\text{ in}^4$

$\Delta_{max} = \frac{5 \times .324 \times (45 \times 12)^4}{384 \times 29000 \times 14900} = .830'' \leq .844''$ ✓

• Double check bending stress

corrected dead load: $.292 \times 8 \times 45 = 105\,k$ (increase by 42.8)

∴ dead load increase per beam = 5.35 k

Corrected Moment = 1721 + 5.35 x 22 = 1839 k·ft

$S = \frac{M}{\sigma_s} = \frac{(1839 \times 12)}{(70 \times .55)} = 573\text{ in}^3 \leq \frac{14858}{(32.0/2)} = 929\text{ in}^3$ ✓

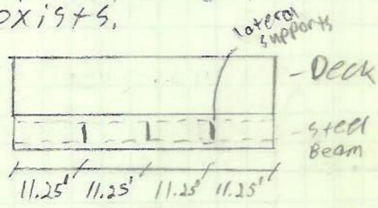
– 8 W30x292 (A709, Grade HPS 70W) beams satisfy the allowable stress & deflection.

1.2.2 (11)

1.2.2.3 Lateral Bracing due to wind loading & Longitudinal Forces

Since the beam depth is less than 42" cross beams are not required (AREMA, 20'(06))

For Pre-cast concrete decks without cross frames a minimum of I-shaped shall be used spaced at not more than 12', where no top lateral support exists.



Info of bracing:

5 8' beams
20 3' beams
10 4' beams

Compressive forces for lateral bracing: $(W + WL + .025LF)$
$= 6.93k + 13.5k + .025 \cdot 168k / 5 \text{ members} = 4.93k$

$\sigma_{all} \geq \sigma_{AC} \rightarrow .55 \times 50 \text{ ksi} \geq \frac{.77k}{A_{beam}} \rightarrow A_{beam} \geq \frac{4.93}{.55 \times 50} = .179 \text{ in}^2$

Since $120 \geq \frac{l}{r_y} \rightarrow r_x \geq \frac{l}{120} = \frac{3' \times 12''/'}{120} = .3 \text{ in}^3$

Height of beam needs to be close to but less than:

main member − 2·web thickness = 32" − 2·2.64 = 26.72"

Select a W24x131 ($d = 24.5''$, $A = 38.6 \text{ in}^2$, $r_y = 2.97''$)
(A992 beams)

Correction to dead weight of superstructure:

$.131 \text{ k/ft} \cdot (5 \cdot 8' + 20 \cdot 3' + 10 \cdot 4') = +18.3k$

Corrected moment (per stringer): $1839 \text{ k}\cdot\text{ft} + \left(\frac{18.3k}{8 \text{ beams}}\right) \cdot 22' = 1906 \text{ ft}\cdot\text{k}$

$S = \frac{M}{\sigma \cdot S} = \frac{1906 \times 12}{70 \times .55} = 594 \text{ in}^3 \leq 929 \text{ in}^3$ ✓

Since the design loads are 4.93k, they are small enough for a welded connection, as long as the shear force is less than: $.35 F_y = .35 \cdot 50 \text{ ksi} = 17.5 \text{ ksi}$

$\sigma_{all} \geq \sigma_s \rightarrow 17.5 \text{ ksi} \geq 4.93k / 38.6 \text{ in}^2 = .128 \text{ ksi}$ ✓

The beam lengths need to be adjusted to account for the stringer thickness: 1.02" ≈ 1" (welding will take care of the .02")

So use: 5 x 7'11" beams + 20 x 2'11" beams + 10 x 3'11" beams.

1.2.3 Superstructure: Reinforced concrete Deck

(12)

Reinforced concrete Deck (LFD)

Minimum Deck thickness:

AREMA = 6.0" AASHTO = 8.0"

Selected thickness = 9.0" (To be conservative)

1.2.3.1 · Factored Shear & Moment calculations (per foot of slab)

Group I: $1.4(D + \frac{5}{3}(L+I)) = 1.4D + \frac{7}{3}L + \frac{7}{3}I$

Laterally Distributed Dead Load

① − Ballast & track ties $= .120 \times 1 \times 1\frac{7}{12} = .190\ k/ft \xrightarrow{\times 1.4} .266\ k/ft$

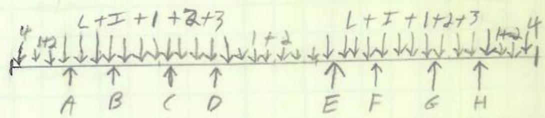
② − Concrete Deck $= .150 \times 1 \times \frac{9}{12} = .113\ k/ft \xrightarrow{\times 1.4} .158\ k/ft$

③ − Track rails, inside guardrails, & fastenings
$= .200 \times 1 = .200$ kips $\xrightarrow{\times 1.4} .28$

④ − concrete wall $= .150 \times 1 \times \frac{9}{12} \times 2\frac{7}{12} = .291\ k/ft \xrightarrow{\times 1.4} .407\ k/ft$

Live load: $8\ k/ft \xrightarrow{\times 7/3} 18.7\ k/ft$

Impact load $= LL \times .362 \times .9 = 2.61\ k/ft \xrightarrow{\times 7/3} 6.09\ k/ft$



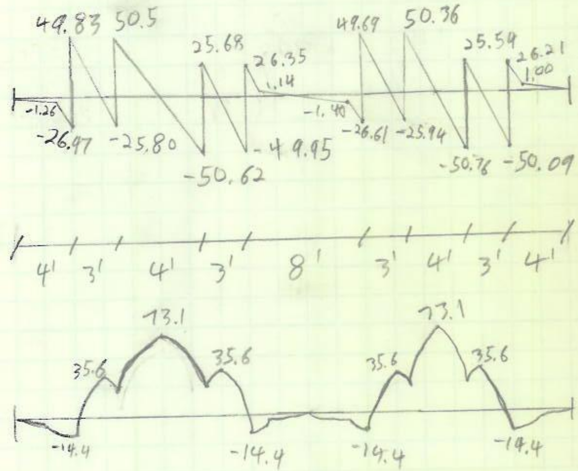
All supports are assumed to support the same load

$\Sigma F_y = 8 \cdot F_R - 2(.407 \times 1) - 10(.266 + .158) - 24(.266 + .158 + 18.7 + 6.09) - .28 \times 2$

$F_R = 76.3\ k$

1.2.3 (V3)

1.2.3.2 Lateral Deck Shear & Moment Diagrams



Shear Diagram (kips)

Moment Diagram (k·ft)

1.2.3.3 Design for Positive Flexure in Deck

Assume #10 bars: diameter = 1.27" Area = 1.27 in²

$de = h - \text{cover} - \frac{\text{diam}}{2} = 9.0 - 1.5 - \frac{1.27}{2} = 6.87$ " (AREMA, 2000)

$\phi = .90 \quad b = 12.0" \quad M_P = 73.1$ k·ft

$R_n = M_P / (\phi_K \cdot b \cdot de^2) = (73.1 \times 12) / (.9 \times 12 \times 6.87^2) = 1.72$ k/in²

$F_y = 60$ ksi $\quad f'c = 5$ ksi

$\rho = .80\left(\frac{f'c}{F_y}\right)\left[1.0 - \sqrt{1.0 - \frac{2 \cdot R_n}{.80 f'c}}\right]$

$\rho = .80\left(\frac{5}{60}\right)\left[1 - \sqrt{1 - \frac{2 \times 1.72}{.80 \times 5}}\right] = .0417$

$A_s = \rho \cdot b \cdot d_e = .0417 \times \frac{12}{ft} \times 6.87 = 3.44$ in²/ft

Required bar spacing = 4.43" say 4" (based on #10 bars w/ 12" width of slab)

$\varepsilon_u = .003, \ \varepsilon_t = .004 \therefore \frac{\varepsilon_u}{\varepsilon_u + \varepsilon_t} = .429$

$F_{ye} = 1.27 \cdot 60 = 76.2$ k

$a = 76.2 / (.80 \times 5 \times 4) = 4.76 \qquad \beta_1 = .80$

1.2.3 (14)

$c = a/\beta_1 = 5.95$ $c/d_e = .87 \nleq .42$

Try #8 bars: diam = 1.00" area = .79 in²

$d_e = 9.0 - 1.5 - \frac{.79}{2} = 7.11"$

$R_n = 73.1 \times 12 / (.9 \times 12 \times 7.11^2) = 1.61\ k/in^2$

$\rho = .80(\frac{5}{60})[1 - \sqrt{1 - \frac{2 \times 1.61}{.80 \times 5}}] = .0372$

$A_s = .0372 \times 12 \times 7.11 = 3.17\ in^2/ft$

Required spacing = 3.0"

$F_{ye} = .79 \times 60 = 47.4\ k$

$a = 47.4 / (.80 \times 5 \times 3.09) = 3.83$

$c = 3.83 / .80 = 4.79 \rightarrow c/de = .67 \nleq .42$

Try #5 bars: diam = .625 Area = .31

$d_e = 9.0 - 1.5 - \frac{.31}{2} = 7.35"$

$R_n = 73.1 \times 12 / (.9 \times 12 \times 7.35^2) = 1.50\ k/in^2$

$\rho = .8(\frac{5}{60})[1 - \sqrt{1 - \frac{2 \times 1.50}{.8 \times 5}}] = .0333$

$A_s = .0333 \times 12 \times 7.35 = 2.94\ in^2/ft$

Required spacing = 1.3" * Too short

Redesign deck: new thickness = 12"

- Correction to dead load

② $.150 \times 1 \times 1 = .150\ k/ft \rightarrow .210\ k/ft$

④ $.150 \times 1 \times 1 \times 2\frac{7}{2} = .388\ k/ft \rightarrow 1.55\ k/ft$

$\Sigma F_y = 0 \therefore F_y = 76.9\ k$

Shear change - minimal

Moment change → assume new M = 74.0 k·ft

1.2.3 (15)

Try #8 bars : diam = 1.00" area = .79 in²

$d_e = 12.0 - 1.5 - \frac{.79}{2} = 10.11''$

$R_n = 740 \times 12 / (.9 \times 12 \times 10.11^2) = .80\ k/in^2$

$\rho = .8\ (\frac{5}{60})\left[1 - \sqrt{1 - \frac{2 \times .80}{.8 \times 5}}\right] = .0150$

$A_s = .0150 \times 12 \times 10.11 = 1.82\ in^2$

Required spacing = 5.21" Say 5"

$F_{ye} = .79 \times 60 = 47.4\ k$

$a = 47.4 / (.80 \times 5 \times 5.21) = 2.27$

$c = 2.27/.8 = 2.84 \rightarrow \frac{2.84}{10.11} = .28 \leq .42$ ✓

optomize deck: 11" thickness

using #8 bars:

$d_e = 11.0 - 1.5 - \frac{.79}{2} = 9.11''$

$R_n = 740 \times 12 / (.9 \times 12 \times 9.11^2) = .99\ k/in^2$

$\rho = .8\ (\frac{5}{60})\left[1 - \sqrt{1 - \frac{2 \times .99}{.8 \times 5}}\right] = .0193$

$A_s = .0193 \times 12 \times 9.11 = 2.11\ in^2$

Required spacing = 4.49" say 4"

$a = 47.4 / (.8 \times 5 \times 4'') = 2.96$

$c = 2.96/.8 = 3.70 \rightarrow \frac{3.70}{9.11} = .41 \leq .42$ ✓

Positive Flexure Design = 134 #8 bars (60ksi) @ 4"

(16)

1.2.3

1.2.3.4 Design for Negative Flexure in Deck

Assume #5 bars: diameter = .625" area = .31 in²

$d_e = h - cover - \frac{diam}{2} = 11.0 - 2.0 - \frac{.625}{2} = 8.69"$

$\phi_f = .90$ $b = 12.0"$ $M_n = -15.0$ (increase due to new slab)

$R_n = -M_n / (\phi_f \cdot b \cdot d_e^2) = 15.0^{k\cdot ft} / (.9 \times 12 \times 8.69^2) = .221$ k/in²

$\rho = .80\left(\frac{f'c}{f_y}\right)\left[1.0 - \sqrt{1.0 - \frac{2 \times R_n}{.80 f'c}}\right]$

$\rho = .80\left(\frac{5}{60}\right)\left[1.0 - \sqrt{1.0 - \frac{2 \times .221}{.80 \times 5}}\right] = .00379$

$A_s = \rho \cdot b \cdot d_e = .00379 \times 12 \times 8.85 = .402$ in²/ft

Required bar spacing = $.31 \times 12 / .402 = 9.25"$ say 9"

$F_{ye} = .31 \times 60 = 18.6$ k

$a = 18.6 / (.80 \times 5 \times 9) = .517$ $\beta = .80$

$c = .517 / .80 = .646$

$.646 / 8.85 = .07 \leq .42$

Negative Flexure Design = 47 #5 bars (60 ksi) @ 9"

* At this point in the design a correction is needed, because the minimum spacing (on center) allowed is 6" (AREMA, 2010b)

1.2.3 (17)

1.2.3.5 Correction to Positive Flexure Design

Minimum Spacing = 6" → Assume #11 bars
(Area = 1.56 in² Diameter = 1.41")

$d_e = 11.0 - 1.5 - \frac{1.41}{2} = 8.80''$

$R_n = (74.0 \times 12) / (.9 \times 12 \times 8.8^2) = 1.06$

$\rho = .80 (\frac{5}{60}) [1 - \sqrt{1 - \frac{2 \times 1.06}{.80 \times 5}}] = .0209$

$A_s = .0209 \times 12 \times 8.8 = 2.21$ in²/ft

Required spacing = 8.47" → say 8"

$F_{ye} = 1.41 \times 60 = 84.6$ k

$a = 84.6 / (.80 \times 5 \times 8) = 2.64$

$c = 2.64/.80 = 3.30$ $\quad c/d_e = 3.3/8.8 = .38 \leq .42$ ✓

#11 bars (60 ksi) @ 8"

1.2.3.6 Correction to Negative Flexure Design

Use 8" spacing instead of 9"

$a = 18.6 / (.80 \times 5 \times 8) = .581$

$c = .547/.80 = .718$ $\quad .718/8.85 = .08 \leq .42$ ✓

#5 bars (60 ksi) @ 8"

Double check Bending Stress in Beams

Corrected Dead Load: $(9 + 308 + \frac{3}{12} \times 45 \times 36 \times .15 + 195 + .292 \times 8 \times 45)/8$
= 84.7 k per beam (increase by 7.59 k per beam

Corrected Moment: $1839 + 7.59 \times 22.5 = 2000$ k·ft

$S = \frac{2000 \times 12}{(70 \times .55)} = 623$ in³ ≤ 929 ✓

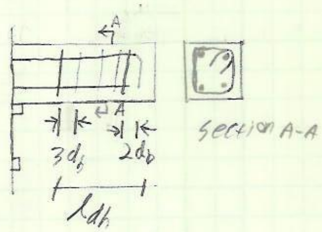
1.2.3 (18)

1.2.3.7 Design for overhang in Deck

Same as negative flexure in Deck:

#5 bars (60 ksi) @ 9"

Development of Standard Hooks for lateral support



$d_b = .625''$

$l_{dh} = 1200 \times d_b / \sqrt{f'_c}$
$= 1200 \times .625 / \sqrt{5000} = 10.6''$

6 hooks are required laterally for each beam.

depth of hook: $12 d_b = 12 \times .625 = 7.5''$

1.2.3 (19)

1.2.3.8 Bottom Longitudinal Distribution Reinforcement

Effective Span width(S_e) = 8' (highest span width)

$A_s\% = 220/\sqrt{S_e} = 220/\sqrt{8} = 77.8\%$

$77.8\% \nleq 67\% \rightarrow$ use 67%

Primary design used #11 bars @ 8" (A = 1.56in² Diam=1.41")

$A_s = 1.56 \times \frac{12}{8} = 2.34\ in^2/ft$

$A_s = A_s\% \times A_s = .67 \times 2.34 = 1.57\ in^2$ (LRFD, 2011)

Spacing = $1.57/1.57 \times 12 = 12''$

Spacing can't excede slab thickness (11")

Assume 10" spacing

1.2.3.9 Top Longitudinal Distribution Reinforcement

Primary design used #5 bars @ 8" (A=.31in², Diam=.625")

$A_s = .31 \times \frac{12}{8} = .465\ in^2/ft$

$A_s = .67 \times .465 = .31\ in^2$ (LRFD, 2011)

Spacing = $.31/.31 \times 12 = 12''$

Assume 10" spacing

Check Longitudinal distribution requirements

$.01 \leq \frac{A_s}{A_g} \leq .08 \rightarrow \frac{(1.56 + .31)}{11 \times 10} = .02$ ✓

Web Reinforcement

- No longitudinal support needed due to beams
- No lateral support needed for slabs.

1.3.1 Substructure: Design Loads (20)

Design Loads: Substructure (Per abutment)

(a) Dead Loads

- Superstructure: $(9.00 + 308 + 195 + .150 \times 45 \times 36 \times \frac{3}{12} + 8 \times 45 \times .292)/2 = 339^k$

$+ \frac{18^k}{2}$ (lateral bracing) $= 348^k$

- Substructure: Depends on situation

(b) Live Loads

- L = 1056 / 2 abutments = 528 k

(c) Impact Load = 0 k, not considered for substructure (AREMA, 2000)

(d) Centrifugal Force = 0k

(e) Wind Load on Structure

w = .045 k/ft² × 20' × 4' = 3.6 k

(f) Wind Load on Live Load

WL = 13.5 k / 2 abutments = 6.8 k

(g) Longitudinal Load

LF = 168 k/2 abutments = 84 k

(h) Earthquake Load

No analysis determined necessary

(i) Snow & Rain Loads

OF = 115 k/2 abutments = 57.5 k

(j) Buoyancy

Assumed 0

(k) Earth Pressure

- Backfill: $\gamma = .125$ k/ft³ $\phi = 28°$

1.3.1 (21)

– Surcharge

$80k / ((9' \text{ tie} + .5' \text{ ballast}) \times 5' \text{ axle spacing}) = 1.684 k/ft^2$

Effective height $= 1.684/.125 = 13.5'$

– Active Earth Pressure

· For 19' of Retaining wall:

$P = \frac{1}{2}\gamma \times h(h+2h')\frac{1-\sin\phi}{1+\sin\phi} = \frac{1}{2}\times .125 \times 23(23+2\times 13.5)\times\frac{1-\sin(28)}{1+\sin(28)}$

$P = 26.0\ k/ft \quad \therefore P_1 = 494\ k$

Location of Earth Pressure with Surcharge

$Y = \frac{h^2+3h'\times h}{3(h+2h')} = \frac{(23)^2+3\times 13.5\times 23}{3(23+2\times 13.5)} = 9.74'$ above ground

· For 17' of Retaining wall:

$P = \frac{1}{2}\gamma\times h^2\times\frac{1-\sin\phi}{1+\sin\phi} = \frac{1}{2}\times .125\times 23^2\times\frac{1-\sin(28)}{1+\sin(28)}^{*} = 11.9\ k/ft$

$\therefore P_2 = 202k \quad Y = \frac{23}{3} = 7.67'$ above ground

*28° → Assumption based on backfill property (AREMA, 2000)

Average Earth Pressure over entire wall

$P = 26.0\times\frac{19}{36} + 11.9\times\frac{17}{36} = 19.3\ k/ft$

$Y = \frac{494\times 9.74 + 202\times 7.67}{494+202} = 9.14'$

1.3.1 (22)

Loading Combination (LFD): substructure

- **Group I**

$1.4(D + \frac{5}{3}(L + I) + CF + E + B + SF)$

$1.4(339 + \frac{5}{3} \times 528 + 139) = \boxed{1900\ k}$ Governs

- Group IA

$1.8(D + L + E) = 1.8(339 + 528 + 139) = 1810\ k$

- Group III

$1.4(D + L + E + 0.5W + WL + LF)$

$= 1.4(339 + 528 + 139 + .5 \times 3.6 + 6.8 + 84) = 1540\ k$

- Group IV

$1.4(D + L + E + OF) = 1.4(339 + 528 + 139 + 57.5) = 1490\ k$

- Group VI

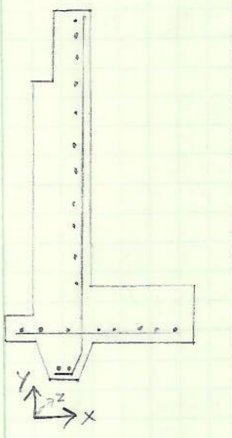
Group III $+ 1.4 \times OF = 1540 + 1.4 \times 57.5 = 1620\ k$

1.3.2 - Substructure: Reinforcing the Retaining wall

(23)

Reinforcement of Abutment Retaining Wall

Figure



- Reinforcing the Footing

Maximum Reinforcement = .008
↳ .008/2 (only half support) = .004

$\frac{M_u}{\phi b d^2} = 235^{*} PSI$

$d_e = \sqrt{\frac{1.6 \cdot E \cdot Y/12}{\phi \cdot 12 \cdot \frac{M_u}{\phi b d^2}}} = \sqrt{\frac{1.6 \times 176000 \times 12}{.9 \times 12 \times 235}} = 36.5''$

↳ Required change to structure

Front toe new height = 42'', not 24''

→ Area of required steel: $.004 \times 12'' \times 36.5'' = 1.75\ in^2/ft$

∴ Assume No. 10 bars spaced at 8'' for support in the X-Direction (excluding the one in the subtoe)

- Lateral (Z-direction) support for Footing

* Since Lateral support is secondary, use 67% of the primary design.

$.67 \times 1.75 = 1.17\ in^2/ft$

∴ Assume No. 8 bars spaced at 8''

Reinforcing the wall

Maximum Reinforcement = .004 ∴ $\frac{M_u}{\phi b d^2} = 235\ PSI$

$d_e = 48'' - 19'' - 3'' - 1'' = 25''$

$A_s = .004 \times 25'' \times 12'' = 1.2\ in^2/ft$

∴ Assume No. 8 bars spaced at 8'' in the Y direction and extending into the subtoe.

- Lateral support ⇒ $.67 \times 1.2 = .80\ in^2/ft$

∴ Assume No. 7 bars spaced at 8''

(1.4) Bridge Connections (24)

1.4 Pin & Roller supports

- Calculation of total displacement at mid-span.

Live + Impact Loading = .833"

Dead Load (per beam): $\frac{84.7 + 2.3^k}{45'}$ = 1.93 k/ft (lateral bracing)

$\Delta_{DL} = 5 \times (1.93^{k/'} \times \frac{1'}{12''}) \times (45 \times 12)^4 / (384 \times 29000 \times 14900) = .455''$

$\Delta_{LL} = .833''$ ∴ $\Delta_{TO} = \Delta_{DL} + \Delta_{LL} = 1.29''$

- Angle of Deflection

$\theta_T = \frac{wL^3}{24EI} = \frac{\frac{(1.93 + 4.00)^{k/'}}{12''/'} \cdot (45' \times 12''/')^3}{24 \cdot 29000 \cdot 14900} = .00750$ radians

$\frac{wL^3}{24EI}$

Max allowable bearing pad stress = 1.0ksi

- Bearing Pad Design

Required thickness = T = $12.5 \times \theta_T \times L$

Pad Area = $[1.4(895 + \frac{5}{3}(1056 \times 1.3258))/(8 \times 2)]/1.0 = 282 in^2$

Pad Length = $282 in^2$ / 15in (width of Beam) = 18.8" → 19"

Pad thickness = T = $12.5 \times \theta_T \times L_m$

T = 12.5 × .00750 × 19 = 1.78" say 2"

Fabric Pad design = 16" × 19" × 2"

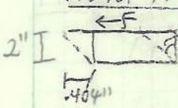
1.4 (25)

Thermal Expansion of Concrete & Steel

$\Delta L = L_i \alpha \Delta T = 45' \times 12''/ft \times 6.5\times10^{-6}/^\circ F \times 115^\circ F$ (Roeder, 2002) $= .404''$

$\alpha_{steel} \approx \alpha_{concrete}$, and assume $\mu = .30$ for bearing Pad

Axial Stress in steel beams: $F_f = D \times \mu = \left(\frac{678+18}{16 \text{ connections}}\right) \times .30 = 13.1k$



$\gamma = \tan^{-1}\left(\frac{.404}{2}\right) = .199$

Figure Shear Force in bearing Pad

$\phi = .85 \therefore \frac{13.1k}{.85 \cdot 50.8 in^2} = .303 \text{ ksi} \leq 38.5 \text{ ksi}$ ✓

Shear force in Bearing Pad: As long as the angle (γ) doesn't exceed 45°, the shearing stress will be acceptable.

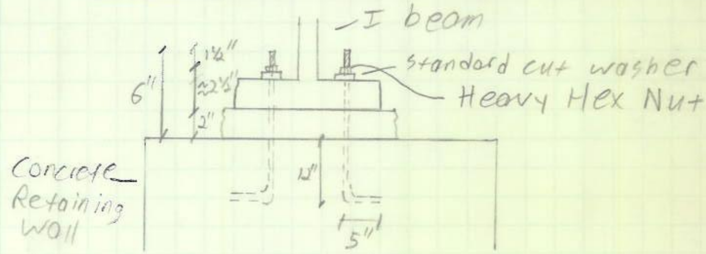
$\gamma = .199$ radians $= 11.4^\circ < 45^\circ$ ✓

Assume 4 bolts, Diameter = 1.25" & F_y = 120 ksi

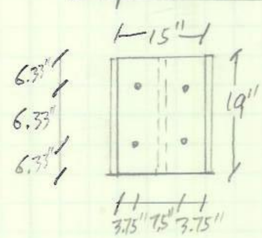
$A = \frac{F_t}{P_i} = 120/105 = 1.14 \text{ in}^2$

$A = 4 \text{ bolts} \times \frac{1.25^2}{4} \times \pi = 4.91 \text{ in}^2 \geq 1.14 \text{ in}^2$ ✓

Dimensions of Bolted Pin Connectors



Top view of Anchor Bolt Locations



1.4 (26)

-Check Bearing Pads against Dead, Live, & Impact Loading

$1.4(D + \frac{5}{3}(L + IL)) = 4490\,k$

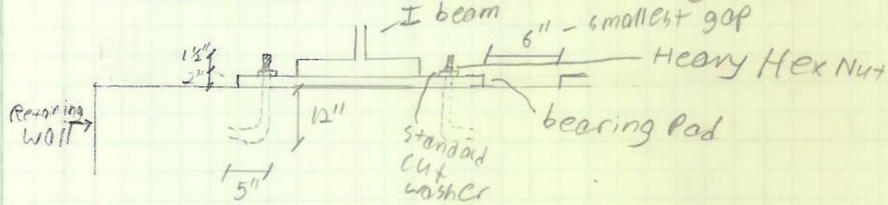
$F_f = (\frac{4490}{2}) \times .85 \times .30 = 572\,K$

-4 Bolts, Diameter = 1.25" & $F_y = 120\,ksi$

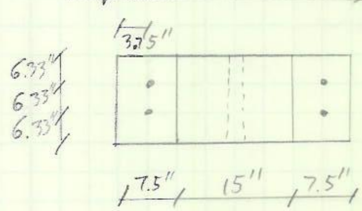
$A = \frac{F_f}{F_y} = 572/120 = 4.77\,in^2$

$A = 4\,bolts \times \frac{1.25^2}{4} \times \pi = 4.91\,in^2 \geq 4.77\,in^2$

Dimensions of Bolted Bearing Pads



Top View of Anchor Bolt Locations



Adjust original Bearing Pads to accomodate 1.73" thermal expansion:

Pin Bearing Pads: 16" x 21"
Roller Bearing Pads: 30" x 21"

C-2: Hillman Composite Beam Design

(1)

Design Alternative: Hillman Composite Beam (HCB)

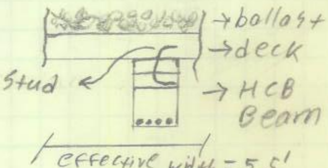
* Note: This is only a rough design with many assumptions. It is meant to illustrate what the beams will roughly look like.

LRFD estimated loading: $1.4(D + \frac{5}{3}(L + IL))$

Dead Load Assumption: 0.100k/ft for Beams:

$$1.4\left[\underbrace{\left(\tfrac{11}{12}\right)' \cdot 5.5' \cdot .145\tfrac{k}{ft^3}}_{\text{precast deck}} + \underbrace{.1\tfrac{k}{ft}}_{\text{HCB Beam estimate}} + \underbrace{.2\tfrac{k}{ft}}_{\text{rail \& ties}} + \underbrace{.12\tfrac{k}{ft^3} \cdot 5.5' \cdot 1.583'}_{\text{Ballast}} + \underbrace{\tfrac{5}{3}\left(\tfrac{1056 \times 1.3258k}{8\ \text{beams} \cdot 45'}\right)}_{\text{Live + Impact load}}\right]$$

$= 12.0\ ^k/_{ft}$

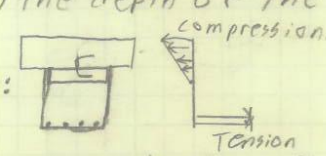


Loading assumed as uniform distribution

$$M = \frac{12\ ^k/_{ft} \cdot (45')^2}{8} = 3037.5\ ft\cdot k = 36450\ in\cdot k$$

There are three components for design consideration: 1) the amount of concrete present, 2) the amount of steel present 3) the depth of the beam.

Assume Partial Composite Action:



Determine amount of concrete required based on Compressive Forces

$\sigma = \frac{MC}{I}$

Y = depth of concrete in beam

Find centroid: $C = \frac{\Sigma Y \cdot A}{\Sigma A} = \frac{(Y + \frac{11''}{2})(5.5' \times 12 \times 11) + \frac{Y}{2} \cdot Y (\text{Assumed width} = 16'')}{5.5 \times 12 \times 11 + Y \cdot 16}$

$$C = \frac{8Y^2 + 66Y + 363}{16Y + 726}$$

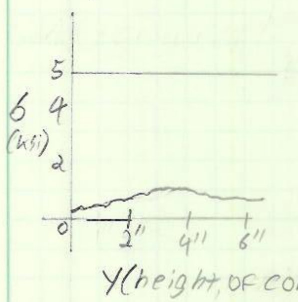
Find Moment of Inertia: $\Sigma I + A \cdot d^2$

$I_1 = \frac{1}{12} \cdot b \cdot h^3 = \frac{4Y^3}{3}$ $\qquad I_2 = \frac{1}{12} \cdot bh^3 = \frac{1}{12} \cdot 66'' \cdot (11'')^3 = 7320\ in^4$

$$\Sigma I = \left[\frac{4Y^3}{3} + (Y \cdot 16) \cdot \left(\frac{Y}{2} - C\right)^2\right] + \left[7320 + 726 \cdot (Y + 5.5 - C)^2\right]$$

(2)

With an expression for C & I, $M = 36450$ in-k, $6_c = 5$ ksi. The equation $6 = Mc/I$ is put into a graphing calculator where $Y = 6$ and $X = Y$ (height of concrete). Another graph ($Y=5$) is used and where they intersect will be the required depth.



As it can be seen, the lines don't intersect. The largest value only breaks 1.0 ksi, confirming the concrete deck is capable of holding the bending stresses present.

Due to this graph, the selected depth will be 5", based on previous designs (Hillman, 2011).

Steel Required (270 ksi prestressing steel)

Through a personal communication with John Hillman, the group learned that one layer of prestressing strand is used for the beam design, with a strength of 270 ksi.

Required Size of Beam

Through the personal communication with John Hillman listed above, the group learned that the average depth of the beams are equal to $\frac{\text{Span Length}}{(10 \text{ or } 12)}$.

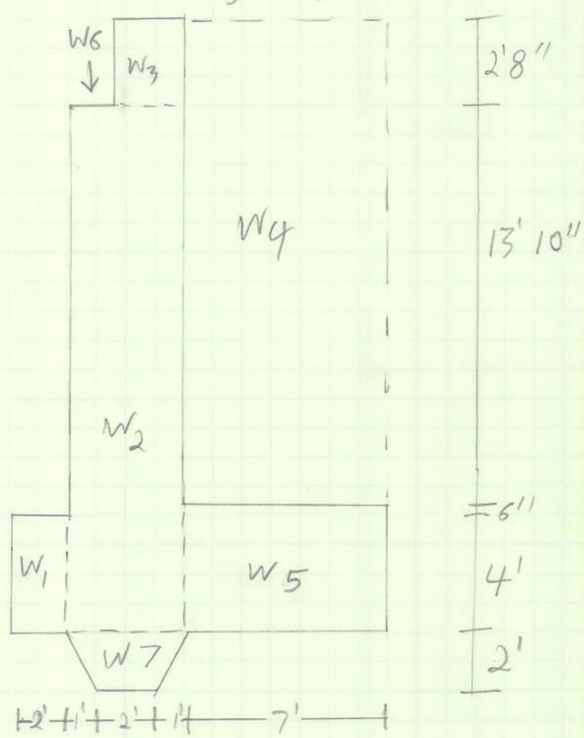
This wouldn't provide sufficient clearence and some beams have been designed up to a depth of span length/25 (Hillman, 2011).

Keeping this in mind, the group would like to recommend a depth of span length/20, which is 2'4".

If this isn't feasable then a depth closer to 3', where the deck is thinner to accomodate composite action.

C-3: Overturning Moment for the Substructure

Supporting Figure for Substructure



W_1, W_2, W_3, W_5, W_7 = Substructure weight

W_6 = Load from superstructure

W_4 = Earth Load

Overturning Test 1 - Structure after construction (no Dead Load or Live/Impact Load)					
Component Weights	**W, Kips**	**x, ft**	**Mr = W*x, K-ft**		
W1: 2 x 4 x.15	1.20	1.00	1.20		
W2: 4 x 18.33 x .15	11.00	4.00	43.99		
W3: 2.25 x 5.33 x .15	1.80	5.13	9.22		
W4: 7 x 16.5 x .125	14.44	9.50	137.16		
W5: 4.5 x 7 x .15	4.73	9.50	44.89		
W7: 6 x .15	0.90	4.00	3.60		
Sum (W)	34.06		240.05		
Overturning Moment: M0			**Resultant Distance = a (ft)**		
M0 = 8.15 x 6.33	91.27		4.37		
				5.20	
Factor of Safety against overturning	**2.63**		**Maximum Soil Pressure in KSF ((4*13'-6a)*W/13'^2**		
Overturning Test 2 - Structure w/ Superstructure Dead Load and Surcharge					
Component Weights	**W, Kips**	**x, ft**	**Mr = W*x, K-ft**		
W1: 2 x 4 x.15	1.20	1.00	1.20		
W2: 4 x 18.33 x .15	11.00	4.00	43.99		
W3: 2.25 x 5.33 x .15	1.80	5.13	9.22		
W4: 7 x (16+19) x .125	31.06	9.50	295.09		
W5: 4.5 x 7 x .15	4.73	9.50	44.89		
W6: Superstructure DL	9.42	2.75	25.90		
W7: 6 x .15	0.90	4.00	3.60		
Sum (W)	60.10		423.89		

Overturning Test 3 - Structure w/ Superstructure Dead, Live, and Breaking Loads				
Component Weights	**W, Kips**	**x, ft**	**Mr = W*x, K-ft**	
W1: 2 x 4 x.15	1.20	1.00	1.20	
W2: 4 x 18.33 x .15	11.00	4.00	43.99	
W3: 2.25 x 5.33 x .15	1.80	5.13	9.22	
W4: 7 x (16+19) x .125	31.06	9.50	295.09	
W5: 4.5 x 7 x .15	4.73	9.50	44.89	
W6: Superstructure DL + LL	38.75	2.75	106.56	
W7: 6 x .15	0.90	4.00	3.60	
Sum (W)	89.43		504.55	
Overturning Moment: M0			**Resultant Distance = a (ft)**	
M01 = 19.7 x 8.15	176.40		2.21	
M02 = (168/36) x 26	130.67			27.00
Mt = M01 +M02	307.07			
Factor of Safety against overturning	**1.64**		**Maximum Soil Pressure in KSF (2*W)/(3*a)**	

Appendix D: Cost and Time Estimate

Time & Cost Estimates						
Note = Unless listed, the below costs include: Material, Labor, Equipment, %10 Overhead and profit						
Geotechnical Investigations	Quantity	P(Daily output)	N(Cost)	Duration (Days)	Cost Estimate	Units (for Quantity)
Borings & Initial Field Stake Out/Elevations	1	1	1050	1.00	1050.00	days
Drawings for Boring Details	1	1	372	1.00	372.00	days
Report & Recommendation from P.E.	1	1	847	1.00	847.00	days
Demolition/Removal						
Removing Pavement	63.89	420	7.9	0.15	504.72	Square Yards (SY)
Sidewalk	200.00	325	4.85	0.62	970.00	Cubic Feet (CF)
Tubes	1080.00	1000	3.81	1.08	4114.80	Square Foot (SF)
Ballast	160.00	500	5.55	0.32	888.00	CY
Remove & Re-install, Railway Ties and Track	60.00	50	55.50	1.20	3330.00	Linear Foot (LF)
Excavating Backfill	816.00	256	10.21	3.19	8331.36	CY
Superstructure						
Precast Concrete Deck	5422.50	770.00	16.45	7.04	89200.13	SF
Reinforcing Cost for the Deck:						
#5 bars (including hooks & anchoring)	244.00	170.00	17.00	1.44	4148.00	Each
# 11 bars	110.00	85.00	74.50	1.29	8195.00	Each
Welding Stringers to Deck	360.00	50.00	17.05	7.20	6138.00	LF
Welding Lateral Bracing to Stringers	181.00	50.00	17.05	3.62	3086.05	LF
Steel Stringers W30x292 (A709, Grade HPS 70W)	360.00	1035.00	674.00	0.35	242640.00	LF
Anchor Bolts, Nuts, and Washers	64.00	25.00	47.00	2.56	3008.00	Each
Neoprene Bearing Pads	95.00	20.00	128.00	4.75	12160.00	Each
Lateral Bracings W24x131(A992)	137.00	1050.00	245.00	0.13	33565.00	LF
Cleaning/preparing steel for painting	4223.00	10000.00	0.04	0.42	168.92	SF
Painting Steel (1st to 3rd coat)	4223.00	2000.00	1.89	2.11	7981.47	SF
Substructure						
Cast in Place Reinforced Concrete Retaining Wall	36.00	6.00	1500.00	6.00	54000.00	LF
Cast in Place Concrete Footing	85.00	40.00	300.00	2.13	25500.00	Cubic Yard (CY)
Installing Backfill	9424.80	2200.00	0.85	4.28	8011.08	CY
Compaction	1008.00	3900.00	0.50	0.26	504.00	CY

Reinstallation						
Sidewalk	800.00	600.00	4.08	1.33	3264.00	SF
Roadway	48.89	660.00	12.35	0.07	603.78	Square Yard (SY)
Ballast	2124.00	2500.00	2.45	0.85	5203.80	SF
Sub Total					527785.11	
Structural Engineering Fees					10555.70	
Sales Tax & Social Security					33586.32	
Insurance for Workers					71970.70	
Field Personnel					24000.00	
General Contractors Main Office Expenses					95960.93	
Scheduling					26389.26	
Regulatory Requirements					5277.85	
Quality Control					11665.00	
Field Offices and Storage					15000.00	
Temporary Scaffolding and Platforms					500.00	
Temporary Barricades and Fencing					1000.00	
Roadway Layout crew					2125.00	
City Cost Index Adjustment					79167.77	
Grand Total					904983.63	**Rounded Amount: $905,000**
Average Inflation Rate Based on 2000-2011	2.55					
Adjusted Cost for 2012	971499.93	Rounded = $971,500				
2017	1095366.17	Rounded = $1,095,500				
2022	1219232.41	Rounded = $1,219,000				
2032	1654002.91	Rounded = $1,654,000				