Wildlife Crossing Development
for Highway 1 in Batipa, Panama

WPI · Universidad Tecnológica oteima — Formadores de Líderes · BATIPA FIELD INSTITUTE

Laura Boccio, Hannah Goddard, Samantha Lor, and Megan Olson

Wildlife Crossing Development for Highway 1 in Batipa, Panama

A Major Qualifying Project Report
Submitted to the Faculty of the Department of Civil and Environmental Engineering at
WORCESTER POLYTECHNIC INSTITUTE
In Partial Fulfillment of the Requirements for the
Degree of Bachelor of Science
Submitted: October 10, 2019

By
Laura Boccio
Hannah Goddard
Samantha Lor
Megan Olson

Report Submitted to:

Project Sponsor:
Dr. Francisco Ugel
Universidad Tecnológica Oteima

Project Advisors:
Associate Professor Aaron Sakulich
Professor Tahar El-Korchi
Worcester Polytechnic Institute

Abstract

This project utilized data collection and structural analysis methods to design a wildlife crossing appropriate to the environmental specifications of Highway 1 on the Batipa Peninsula, Panama. Once constructed, the bridge will encourage permeable population flow between previously divided habitats, thus promoting healthy ecosystems. A complete design in both AutoCAD and AutoDesk Revit was provided to Universidad Tecnológica Oteima to pitch the project to potential sponsors for funding and to the Panamanian government for permission to move forward with construction.

Acknowledgments

We would like to extend thanks to the many individuals who aided in the successful completion of this project. First, our project sponsors from Universidad Tecnológica Oteima (UTO): Francisco Ugel and Edmundo Gonzalez. We are extremely grateful for the opportunity to complete this project in Panama, and for our sponsors' continued effort to make themselves available for any questions or concerns we had throughout our preparation term and while we were in country. We would especially like to thank Edmundo Gonzalez, director of Batipa Field Institute, for hosting us in David for three weeks and giving us the necessary local context to complete our project effectively. In addition, we would like to thank Mr. Luis Ríos Espinosa, president of UTO for taking the time to explain the past, present, and future goals of the university and for giving us vital input on our proposed crossing design.

Finally, we would like to thank the staff of Worcester Polytechnic Institute that helped us with the various technical and logistical aspects of the project. Our advisors, Associate Professor Aaron Sakulich and Professor Tahar El-Korchi made themselves available for the many questions that arose during the development of our design. We would like to especially thank Associate Professor Sakulich for our weekly video calls while in Panama and for being extremely supportive and providing us with edits to our paper and pushing us to be the best we can be. In addition, we would like to extend a thank you to Associate Professor Leonard Albano for helping us address structural concerns with our design, and ensuring that we are considering all the necessary forces that will impact our constructed crossing.

Authorship

Laura Boccio
Laura assisted in completing the RISA analysis and AutoDesk Revit renderings. In addition, she assisted in completing the flora and fauna catalog and writing the background (Chapter 2.3) and results.

Hannah Goddard
Hannah completed the AutoCAD drawings for both the initial designs and the final design, and she helped with RISA analysis and AutoDesk Revit renderings. She was also the primary author for the case studies in the background and assisted in writing the results.

Samantha Lor
Samantha was the primary author of the following sections: abstract, acknowledgments, executive summary, background sections (2.1 and 2.2), results for objective 1, conclusion, and professional licensure. She worked with Megan to write the capstone design statement and methodology chapter. Samantha and Megan also completed final edits and formatting.

Megan Olson
Megan created the various tables found throughout the methodology and results, and also performed structural calculations. She was the primary author for the introduction, and she formatted the table of contents, list of figures, list of tables, and bibliography. In addition, she worked with Samantha to write the capstone design statement and methodology. Megan and Samantha also completed final edits and formatting.

Table of Contents

Table of Figures

Table of Tables

Executive Summary

The construction of the Pan-American Highway (Highway 1) in the early 1920's by the United States and Panamanian governments was a project with the goal of extending a roadway from Alaska to Argentina, effectively connecting the two continents [1]. Although this was a groundbreaking infrastructure project that would improve human's ability to travel and transport goods, it has had detrimental effects on the surrounding ecosystems. As humans continue to develop and progress with technological advances, preserving and protecting biodiversity is becoming a hindsight. Development in remote places causes decline in biodiversity through losses in habitat connectivity, wildlife permeability, and natural migration patterns [2]. When wildlife populations are separated by a physical barrier, the exchange of genetic information is inhibited and species cannot flourish. Latin America contains 40% of the world's species, while only covering 13% of the world's land area [2]. According to the International Union for Conservation of Nature's Red List, there are currently 57 critically endangered species in Panama [3].

The variety of rivers, shorelines, jungles, and other biomes within Panama is an important factor to the country's natural environment, creating a rich biodiversity within the region. The country is home to 978 types of avian, 226 reptile species, 220 mammal species, 164 kinds of amphibians, and 125 animal species found nowhere else in the world [4]. Protection of these species is a growing concern for many reasons including medicinal discovery, livelihood of indigenous groups, and exportation of goods. The importance of Panama's biodiversity in the region is even greater when considering its connection with the highly diverse tropical areas in North and South America [5]. Panama makes up this vital portion of the Mesoamerican Biological Corridor, which connects North and South America, and allows for the plentiful exchange of wildlife. Protecting this movement of plants and animals between the Americas is very important because it is this that provides the genetic exchange allowing species to both flourish and evolve. As the natural environment remains at risk due to global climate change, deforestation, and the expansion of man-made infrastructure, more environmental protection efforts have been developing.

Wildlife corridors, also known as biological, habitat, or green corridors, are regions of the natural environment that connect habitats that have been separated by man-made structures or human activities that prohibit wildlife from interacting normally with their surroundings [6]. Man-made structures such as highways, railways, and changes in land-use create fragmentation and habitat loss, cutting off crucial migration routes and increasing mortality through vehicle collisions. Wildlife crossings, a subset of wildlife corridors, are man-made structures that allow for safe passage of animals around obstacles that intersect their habitats. Habitat permeability is greatly improved with wildlife crossing infrastructure by allowing species previously separated by man-made structures to be reconnected.

The type of wildlife crossing developed is usually chosen based on the species and vegetation it serves and the location's landscape. The two main types of wildlife crossings are overpasses and underpasses [7]. Overpasses are typically in the form of bridges but vary in size and design depending on the wildlife that will utilize it. The two main types of overpass designs are landscape bridges and canopy crossings. Similarly, underpasses have two basic forms: large viaducts and small culverts [8]. Each type of crossing has a number of unique properties that makes it suited for specific areas and landscape profiles.

Currently, Highway 1 acts as a physical barrier to the 115 animal species that live in the project area: Batipa [9]. The Batipa Peninsula, located in the Chiriquí Province, approximately 22 kilometers (13.7 miles) southeast of the city of David, is home to a number of environmental protection initiatives carried out predominantly by el Instituto de campo Batipa (BFI) and Universidad Tecnológica Oteima (UTO), programs run by Fundación Batipa. UTO, located in David, is a private university that focuses on technology-based education and prides itself on being committed to the sustainable development of the country. The BFI is a research station whose primary focus of research is protecting the extensive biodiversity of Panama by utilizing their location in Batipa, which is consistent with Panama's vast array of wildlife. Howler monkeys, iguanas, frogs, jungle cats, and more occupy the jungle while a plethora of bird and butterfly species fly above. In addition, the region's reefs are home to a number of fish species along with humpback whales and dolphins. The Batipa peninsula covers approximately 4,000 hectares (9,884 acres) that are divided into the following functionalities:

- 2,000 hectares (4,942 acres) made up of mangroves,
- 1,100 hectares (2,718 acres) dedicated to reforestation efforts,
- 600 hectares (1,482 acres) assigned to wildlife conservation, and
- 300 hectares (741 acres) allotted for agroforestry with livestock [10].

To the north of Batipa runs the Inter-American Highway (Highway 1), which is a modern four lane highway with jersey barriers down the center that runs almost the entire length of Panama. Although driving through lush, fruitful vegetation can be beautiful to those travelling through the country, it has been detrimental to the wildlife in the area as they attempt to cross over the highway, many getting injured and killed. In order to bridge this gap and allow for permeable population flow between the two divided areas, a wildlife crossing structure would enable animals to safely pass from one side of the four-lane highway to the other. Designing an effective wildlife crossing over Highway 1 in the BFI research area would help to minimize the risk of harming the rich biodiversity present in Panama, promote ecological preservation in the community, and spark further projects.

The goal of this project was to design a biological crossing that is appropriate to the wildlife and environmental specifications of Highway 1 on the Batipa Peninsula in Panama. The design included material selection for the structure based on compatibility with the local environment, accessibility to the building materials, and local familiarity of use, in addition to a complete analysis of the structural components of the crossing. The project deliverable was a complete wildlife crossing design in AutoCAD and Revit provided to Universidad Tecnológica Oteima. This design is to be used to pitch the project to potential sponsors for funding and to the Panamanian government for permission to move forward with construction. The project team progressed through the following objectives:

Objective 1: Identify Parameters of Design Through Data Collection
Objective 2: Create and Refine Crossing Design
Objective 3: Deliver Final Design

In order to begin the design process, travel from Panama City to the project site on Batipa peninsula was necessary to survey the project site and take measurements. Through face-to-face discussion with the sponsor and measurement processes, the information needed to properly diagram the wildlife crossing remotely from Panama City was obtained.

In order to create the design to scale and to choose the best location for the structure, the land was first examined using Google Earth and from topographical information provided by Universidad Tecnológica Oteima. Additionally, physical land surveys were conducted by driving along Highway 1, stopping in relevant areas to observe the land and road. Through collection of these data, a correctly scaled design was produced. Additionally, the land surveys around the highway gave insight on the soil conditions, native vegetation, and typical wildlife. Observing the soil helped to determine what type of foundation was required for the crossing and the landscape to ensure that the crossing's vegetation flowed effortlessly into the natural surrounding area. Along the road were various fences, guard rails, and vegetated barriers that were examined for potential use as a funnel for the crossing or for fencing along its edge.

The two main contacts, Dr. Francisco Ugel of UTO and BFI's Coordinator Edmundo Gonzalez, were met with to gain information on their vision of the crossing before the design process began. The stakeholders gave qualitative data on what the crossing should look like, material suggestions, placement relative to Highway 1, and what types of animals to target. To understand which species are present in the area and to guarantee that they were captured within the proposal, an extensive catalog of fauna was created. A catalog for plant species was also created in order to ensure a design with continuity of vegetation across the corridor.

Once all of the necessary data was collected the next step was creation of initial designs, consultation with sponsor, and refinement of the model (Objective 2). The initial design was intended to serve solely as a visual representation of the crossing to show to stakeholders and gain feedback on how they would like the team to proceed regarding proposed location and physical design concerns. Using AutoCAD, a rough outline of the crossing with proposed location, aesthetic design, and size was created and presented to Francisco Ugel and Edmundo Gonzalez. Based on the feedback, the design was further developed to address the stakeholder's desires, needs, and concerns. This visual design was then transformed into a well-developed engineering structure through the use of codes, design criterion, and calculations.

In order to address variable loading conditions, references tailored to these specifications were used. In conjunction with the various references that spoke to specific considerations, the overarching design method used was Load and Resistance Factor Design (LRFD). LRFD is a limit state design method used in structural engineering that ensures a structure is proportioned correctly so as to accommodate all forces likely to act upon it during its use. This design method accounts for variability in load and resistance which provides a uniform level of safety and resistance. For bridge design, The American Association of State Highway and Transportation Officials (AASHTO) published LRFD Bridge Design Specifications, which establishes the framework utilized on this project for load combinations and basic design methods. This manual was a key component in ensuring that the design developed satisfied all limit states.

In addition to referencing literature and performing hand calculations, RISA 3D, a structural analysis software, was utilized. After creating models of the crossing's structural members within the software, loading conditions were applied to the structural configuration in the vertical and, or horizontal directions to simulate the various load combinations that must be considered for design. After inputting the data, RISA 3D analyzed the effects of the loads and determined the moment and shear values that were ultimately used to size structural members. By utilizing this software, the crossing design was ensured to be safe within the requirements established by the load effects.

Once the crossing was properly dimensioned, it was visually represented using Google Earth, AutoCAD, and AutoDesk Revit (Objective 3). In order to first understand the proposed location, an aerial view image was created by super imposing images on Google Earth at the proposed location. Next, the AutoCAD drawings served to give a 2D depiction of the crossing with material cross-sections and key dimension values. In order to give a quality portrayal, various views were made including the crossing's placement on the highway, highway view, crossing view, and close-up of the reinforced concrete arches. After completing the AutoCAD design, a 3D model of the crossing was made using AutoDesk REVIT. This 3D model served to give a more realistic view of the crossing with the surrounding area and vegetation included. Through the various portrayals of the crossing, structural, geotechnical, and construction details were illustrated based on both the needs and wants of stakeholders, and engineering standards of design. The entire bridge design, as well as small details, were depicted with dimensions and materials in order to give an all-encompassing illustration of the proposed design as a final deliverable.

Through discussions with stakeholders and topographical analysis of the area, a greater level of understanding of the current issue was gained and measurements of the highway were obtained. The habitat fragmentation caused by the highway was observed first-hand by the frequently seen roadkill, heavily vegetated surrounding environment, and pro-wildlife preservation graffiti. Through observing the highway, it was noticed that there were small gaps in the jersey barriers approximately every 2 kilometers (1.24 miles). This is one area where animals would not have to go over the barriers to cross the roadway, but even so, it would be extremely unlikely for an animal to identify the gap in the jersey barrier as a safe place to cross. Coordinator of the BFI, Edmundo Gonzalez provided information on soil conditions, potential natural materials for use on the crossing, and which wildlife species to target. Sr. Gonzalez expressed BFI's intense concentration on mitigating the effects that erosion has on the area through the use of conscious agricultural techniques and erosion preventing tactics. In order to make certain that the crossing, once constructed, was not negatively impacting the land's integrity, various strategies were discussed. The method chosen to be implemented on the design was the use of vetiver, a perennial bunchgrass.

The catalogs of flora and fauna that were developed were used for various aspects of the design. The animal catalog helped to determine the potential live loads, of which were determined to be negligible. Through study of the animals travel tendencies (arboreal, terrestrial, etc.) it was also determined an overpass would be the right type of structure to build. The vegetation types were used to determine that the soil backfill height from the crown of the arch should be 2.44 meters (8 feet). This soil depth ruled out the use of most large tree species that could pose threats to the sustainability of the bridge, especially if one were to fall into the highway. With this established soil depth of 2.44 meters (8 feet), vegetation was limited to a maximum height of 3 meters (9.84 feet) and an average root depth of 1.52 meter (5 feet).

Concrete was decided on as the main material to be used for the overpass because it is familiar to and commonly used on Panamanian construction sites. In addition, it is sustainable, cost-effective, and easily accessible. Designing the crossing was a process with a number of steps including a preliminary visual design and refinement based on structural calculations. In AutoCAD two potential crossing profiles were created and presented to stakeholders with proposed location, aesthetic design, and size. The chosen design was developed further using structural analysis to guarantee ability to withstand the forces that will be put on the crossing over time. The man-made fencing for the overpass was designed as a 4.88-meter (16-foot) wall extending up from the arch of each tunnel. Once constructed, these cement walls would be filled with soil backfill, which would fill 50% of this height, about 2.44 meters (8 feet). The remaining 2.44 meters (8 feet) would extend above the soil and act as a barrier for animals that will be using the crossing. In addition to the concrete wall lining the crossing, it is designed with a dense barrier of shrubs and bushes to act as a sound and light barrier for the animals. The two most prevalent plants to be included in this barrier include vetiver to combat erosion and calamondin shrubs, which can grow up to three meters tall and are perfect for helping as a sound and light barrier from the highway.

After completing the crossing design both aesthetically and structurally, it was necessary to represent the proposal in a number of ways that would make the design very clear to stakeholders. Three platforms were used in order to give a visual of proposed location, structural makeup, and functionality. The first deliverable was an image of the proposed crossing location. This was created using photoshop to superimpose an aerial view of the crossing over Google Earth where it would be placed. This location was chosen due to its connectivity potential and location relative to Batipa. In order to provide a technical representation of the crossing, AutoCAD drawings were created with bridge placement, highway view, crossing view, and wing wall with slab specifications. The third drawing was a visualization in AutoDesk Revit that encompasses the structure to scale and aesthetically in its proposed location.

1.0 Introduction

Humanity's continued modification of the environment to fit the needs of society has disrupted natural biodiversity and ecosystem function. Man-made infrastructure, resource extraction, and climate change threaten not only plant and animal communities, but the human race as well. Human dependence on the world's biodiversity can be observed in the variety of flora and fauna species that provide food, medicine, and resources for human development and societal progress [11]. However, as humans continue to develop and progress with technological advances, preserving and protecting biodiversity is becoming a hindsight. Development in remote places causes decline in biodiversity through losses in habitat connectivity, wildlife permeability, and natural migration patterns [2]. When wildlife populations are separated by a physical barrier, the exchange of genetic information is inhibited and species cannot flourish. Latin America contains 40% of the world's species, while only covering 13% of the world's land area [2]. According to the International Union for Conservation of Nature's Red List, there are currently 57 critically endangered species in Panama [3]. Some of the major threats to these species are due to urbanization and housing, logging and wooding, and transportation services [3].

A study completed by the European Commission assessing causes of biodiversity loss identified human activity in the form of land use changes, increased pollution, climate change, and deforestation, to be the leading direct cause of biodiversity loss [12]. Transportation is increasingly becoming a major issue for biodiversity [13]. Highways allow humans to venture with ease to previously remote areas at the cost of disrupting the natural ecosystem. While infrastructure will continue to advance, it is necessary to mitigate the disruption it causes to the natural environment [14]. The urbanization of rural parts of Panama is threatening animal species and risking degradation of the country's rich, vast biodiversity [14].

The construction of the Pan-American Highway (Highway 1) in the early 1920's by the United States and Panamanian governments was a project with the goal of extending a roadway from Alaska to Argentina, effectively connecting the two continents [1]. This expensive and grandiose dream was never fulfilled as the Pan-American Highway is still incomplete at the Darién Gap where Panama borders Columbia. While this large transportation infrastructure project has reaped economic and social benefits, it has had secondary detrimental effects on the wildlife in the jungles and mountains of Panama [15].

The Batipa Field Institute (BFI) research area bordering Highway 1 is home to a diverse mix of wildlife and vegetative species. The BFI spans from the coast of Bahía de los Muertos up through thick mangroves and teak forests, through mountains, and north to the main roadway. Currently, Highway 1 acts as a physical barrier to the 115 animal species that live in Batipa [9]. In order to bridge this gap and allow for permeable population flow between the two divided areas, a wildlife crossing structure would enable animals to safely pass from one side of the four-lane, Pan-American Highway to the other.

Countries such as Canada, Australia, The Netherlands, and the United States have explored strategies to mitigate habitat fragmentation due to human activity, specifically transportation infrastructure, by designing wildlife corridors. The various corridor projects that have been constructed in Banff National Park in Canada since 1997 successfully reduced elk road mortality from 559 deaths per year to just 96 [16]. These projects have demonstrated the potential impact that wildlife crossings can have on wildlife populations near major highways.

Designing an effective wildlife crossing over Highway 1 in the BFI research area will help to minimize the risk of harming the rich biodiversity present in Panama, promote ecological preservation in the community, and spark further projects. Using the successes and pitfalls from case studies, a design specific to Batipa and the Pan-American Highway will be presented to stakeholders to gain funding for initiating a wildlife crossing project.

2.0 Background

The following section will give background information necessary to understand the importance and scope of the project as a whole. The narrative briefly discusses basic information on Panama as a country, such as its history of independence and style of government. It then delves into the importance of Panama's pronounced biodiversity, and discusses environmental efforts within the country that aim to mitigate the negative effects of climate change and man-made infrastructure on Panama's natural environment. To conclude the section, the project goals and specific wildlife crossing considerations are discussed.

2.1 Introduction to Panama

The Republic of Panama is a country located in Central America, bordered to the north by Costa Rica and to the south by Columbia (Figure 1). Through the archaeological study of some of the oldest ceramics found in the Americas, it is estimated that humans have lived in Panama since as early as 12,000 B.C. as hunter-gatherers in self-sustaining communities [17]. In 1538, Panama became a Spanish colony until 1821 when it transformed into a province under Colombian governance before becoming independent in 1903. Panama today is home to an eclectic mix of populations including indigenous Indians, Europeans, Africans, Creoles, and Mestizos; many of these groups being brought to the country during the construction of the Panama Canal. In addition to these main groups, there is also a significant presence of Jewish, Chinese, and Hindu communities [18]. This great diversity is intensified by Panama's frequently travelled shipping route which brings all walks of life throughout the country.

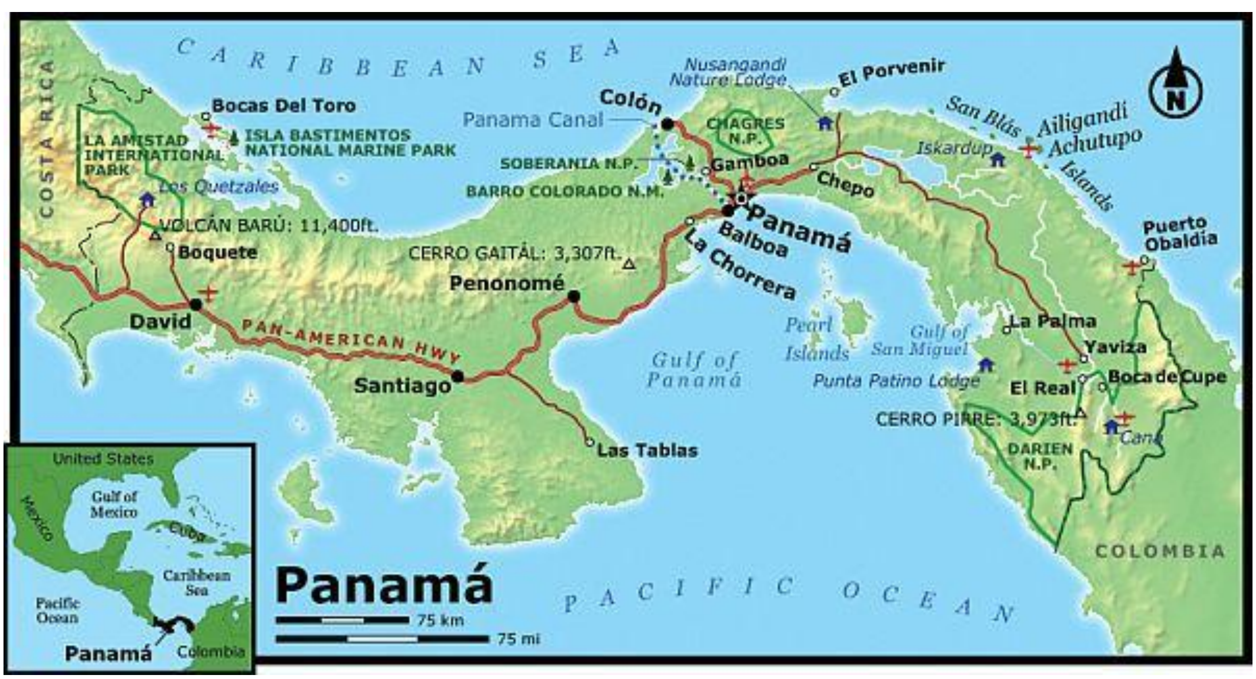


Figure 1: Map of Panama with Major Cities and Pan-American Hwy Route [19].

The Isthmus of Panama is extremely significant in that it connects the North and South American continents by forming a land bridge, and it is home to the famous Panama Canal, which provides a crucial water path for ships and trading. The country is governed by a constitutional representative democracy and has been divided administratively into ten provinces and three indigenous regions, all of which have unique characteristics. By capitalizing on the country's assets through the services industry, Panama has seen a steady increase in gross domestic product (GDP) over the years and is currently looking at a GDP of around $61.84 billion [20]. In addition, further growth will be encouraged through Panama's new canal expansion finished in 2016, which more than doubled the canal's capacity, enabling it to serve larger vessels than ever before [21]. Panama's approximate 74,000-square-kilometer (18,000,000-acre) area is home to roughly 3.8 million people, most of whom are concentrated around the canal and the western region near the city of David [20]. In addition to the millions of people that inhabit the country, it is also home to extremely diverse ecosystems with distinctive flora and fauna.

The variety of rivers, shorelines, jungles, and other biomes within Panama is an important factor in the country's natural environment, creating a rich biodiversity within the region. As Lonely Planet, an informative and inspiring travel magazine reads: "*Imagine a country slightly bigger than Ireland with 21 times more plant species per square kilometer than Brazil*" [4]. The country is also home to 978 types of avian, 226 different reptiles, 220 mammal species, 164 kinds of amphibians, and 125 animal species found nowhere else in the world [4].

The protection of Panama's natural environment and resources is essential for a great number of reasons. To start, the vast number of species in Panama's ecosystems could be a route for medicinal discovery for scientists, and not identifying new species due to rapid habitat destruction is a concern. Many of the plants and animals residing in Panama are also the primary source of livelihood for several indigenous groups that inhabit the region, so the health of those people are reliant on the health of the environment [5]. The financial stability of Panama can also be attributed to the country's environmental health through the trading industry and the agricultural business. Panama exports coffee, bananas, tropical hardwoods, and beef in addition to its involvement in transshipping the goods of other nations [18]. The significance of Panama's biodiversity seems never-ending, which is why protecting it is so important to the intricate balance of the country's conservation efforts.

Panama's dependence on both natural cultivation abilities and geography has sparked conservation and other environmental efforts from various groups within Panama, such as Institute for Tropical Ecology and Conservation, Association for the Conservation of Nature (ANCON), and el Instituto de campo Batipa (Batipa Field Institute or BFI) [22]. In recent years especially, organizations within Panama have put an increasing emphasis on programs aimed towards ecological conservation whether it be protection of the natural environment or native species. The Nature Conservancy is an organization that works with various non-profit organizations, community groups, and private stakeholders to uphold the natural beauty and environmental strength of the country. The Conservancy has been involved in many initiatives since its founding in 1991 from

"*...brokering innovative conservation strategies (such as debt-for-nature swaps), to strengthening protected areas, to helping communities adopt sustainable practices*" [23]. This organization has also conducted research on conservation gaps, which has guided the government's decisions regarding conservation, in addition to their active role in helping 30 local community groups with sustainability efforts. These sustainability efforts include, but are not limited to, wildlife monitoring, ecotourism, production and distribution of organic products, park patrolling, and even fire management efforts which have resulted in a 90% reduction of forest fires within La Amistad National Park [24].

The importance of Panama's biodiversity in the region is even greater when considering its connection with the highly diverse tropical areas in North and South America [5]. Panama makes up this vital portion of the Mesoamerican Biological Corridor, which connects North and South America, and allows for the plentiful exchange of wildlife. Protecting this movement of plants and animals between the Americas is very important because it is this that provides the genetic exchange allowing species to both flourish and evolve. As the natural environment remains at risk due to global climate change, deforestation, and the expansion of man-made infrastructure, more groups such as The Nature Conservancy have been developing and the Panamanian government has been involved in bigger initiatives. Panama is a part of the Mesoamerican Biological Corridor project, one of the largest bioregional conservation programs in the world; according to Lead Environmental Planner, Stephen Dettman, "*...the core idea behind this program is the creation of a series of protected wildlife corridors stretching from southern Mexico to eastern Panama to protect over 769,000 square kilometers* [296,913 square miles] *of land"* [23]. Through these and other efforts Panama has continuously become more involved in protecting its natural environment.

2.2 Area of Focus

The Batipa Peninsula, located in the Chiriquí Province, approximately 22 kilometers (13.7 miles) southeast of the city of David, is home to a number of environmental protection initiatives carried out predominantly by el Instituto de campo Batipa (BFI) and Universidad Tecnológica Oteima (UTO), programs run by Fundación Batipa. UTO, located in David, is a private university that focuses on technology-based education and prides itself on being committed to the sustainable development of the country. Since its founding in 1985 as an educational hands-on training center to becoming recognized as an official university in 2006, UTO has seen a lot of change. Through the years, the mission of the institution has made significant progress towards its goals. Their mission statement proclaims persistence in forming "*…professional leaders and entrepreneurs committed to the sustainable human development of the country through the generation, diffusion, and application of knowledge in areas of teaching, research extension and production.*" [25]. The institutional values of Educational Excellence, Multiculturality, Technological Innovation, Social Responsibility, and Integrity also supplement and reflect the goals of the university [25]. By engaging other institutions and working with organizations such as the BFI, it is UTO's hope to spread their environmental ambitions and inspire others to partake in important environmental initiatives. A 2017 Sustainable Design Solutions Research Paper describes the BFI as follows [26]:

"The Batipa Field Institute was proposed to Oteima University by Dr. Russ Mullen from Iowa State University to serve as a place for hands-on research and education through the global interchange of foreign visitors. This institute provides an opportunity for visiting scientists and students to partake in ongoing long-term studies focused on preserving the unique environment of the Batipa Peninsula, all while integrating biodiversity protection with the rural economic activities of the Batipa company."

The BFI's primary focus of research is protecting the extensive biodiversity of Panama by utilizing their location in Batipa, which is consistent with Panama's vast array of wildlife. Howler monkeys, iguanas, frogs, jungle cats, and more occupy the jungle while a plethora of bird and butterfly species fly above. In addition, the region's reefs are home to a number of fish species along with humpback whales and dolphins. The Batipa peninsula covers approximately 4,000 hectares (9,884 acres) that are divided into the following functionalities:

- 2,000 hectares (4,942 acres) made up of mangroves,
- 1,100 hectares (2,718 acres) dedicated to reforestation efforts,
- 600 hectares (1,482 acres) assigned to wildlife conservation, and
- 300 hectares (741 acres) allotted for agroforestry with livestock [10].

BFI nurtures and promotes Panama's environmental goals through dedication to research and education. The small isthmus of Batipa bordering on "Bahía de los Muertos" (Coffin Bay) to the south has dense mangrove forests on the waterline, teak forests at higher elevations, and wild jungle that serves as a wildlife preserve at the highest elevations (Figure 2). BFI's efforts include conservation of local species as well as implementation of mechanisms that keep them safe, such as man-made reservoirs that protect wildlife during the dry season and biological corridors that serve to aid in animals' navigation of man-made roads.

Figure 2: Map of Batipa Field Institute Region Bordering Hwy 1 and Bahía de los Muertos.

To the north of Batipa runs the Inter-American Highway (Highway 1), which is a modern four lane highway with jersey barriers down the center that runs almost the entire length of Panama. Although driving through lush, fruitful vegetation can be beautiful to those travelling through the country, it has been detrimental to the wildlife in the area as they attempt to cross over the highway, many getting injured and killed. In addition to animal casualties, the highway system also causes issues with habitat permeability and migration patterns. The Inter-American Highway is just a portion of the Pan-American Highway which stretches all the way from Prudhoe Bay, Alaska, to Ushuaia, Argentina, a distance of roughly 48,000 kilometers (30,000 miles); the Inter-American

Highway section spans central America from Nuevo Laredo, Mexico, to Panama City, Panama [27]. The highway ends just south of Panama City, before the Darién Gap, a thickly vegetated, undeveloped region of land, and continues later in Columbia where it extends down into South America (Argentina). As the highway runs through Panama, it cuts through areas of extensive local flora and fauna and regions of forest.

Through publicity and global interchange, the BFI is able to continue its environmental initiatives and efforts effectively, the latest project of which is a biological corridor extending over the Inter-American Highway from the Batipa Peninsula. The BFI anticipates that this pathway will ensure that wildlife has a safe and protected route to travel across the roadway and through the forested area.

2.3 Wildlife Corridors and Design Considerations

Wildlife corridors, also known as biological, habitat, or green corridors, are regions of the natural environment that connect habitats that have been separated by man-made structures or human activities that prohibit wildlife from interacting normally with their surroundings [6]. Man-made structures such as highways, railways, and changes in land-use create fragmentation and habitat loss, cutting off crucial migration routes and increasing mortality through vehicle collisions. Not only are millions of animals killed each year from animal-vehicle collisions, many people are also injured or killed in these accidents. These wrecks are both deadly and expensive with the high cost coming from factors such as vehicle repairs, medical bills, and investigations [28]. Additionally, the fragmentation of corridors by intersecting roads affects the gene flow of wildlife by separating populations, in turn cutting off genetic exchange and encouraging inbreeding [29]. Over time, the lack of gene flow and transfer alleles can cause the two groups to become completely separate populations. Corridors are an excellent solution to these obstacles because they maintain connectivity between habitats which enables migration, colonization, and genetic exchange among populations [6].

Wildlife crossings, a subset of wildlife corridors, are man-made structures that allow for safe passage of animals around obstacles that intersect their habitats. Habitat permeability is also greatly improved with wildlife crossing infrastructure by allowing species previously separated by man-made structures to be reconnected. This increases population's chances of survival because there is more diversity. Natural wildlife migrations also rely heavily on wildlife crossings because without them many animals risk their lives trying to cross busy highways to follow their instinctual desire to migrate. The construction of many of these crossings has encouraged migrations because now more animals are able to bypass roads and highways with minimal risk of vehicular accidents. Even the most simple animal crossings, such as culverts for salamanders in Massachusetts and gullies for turtles in Japan, can help reduce the number of animal deaths by over 50% [30]. Many countries and provinces have already spent the time to design and construct these wildlife crossings while others are in the process of finding more practical and efficient ways to help all kinds of species. Crossings can be constructed as overpasses or underpasses to conquer the targeted obstacle. The type of crossing is usually chosen based on the species and vegetation it serves and the location's landscape. The two main types of wildlife crossings are overpasses and underpasses [7]. Overpasses are typically in the form of bridges but vary in size and design depending on the wildlife that will utilize it. The two main types of overpass designs are landscape bridges and canopy crossings. Similarly, underpasses have two basic forms: large viaducts and small culverts [8]. Each type of crossing has a number of unique properties that makes it suited for specific areas and landscape profiles (Figure 3).

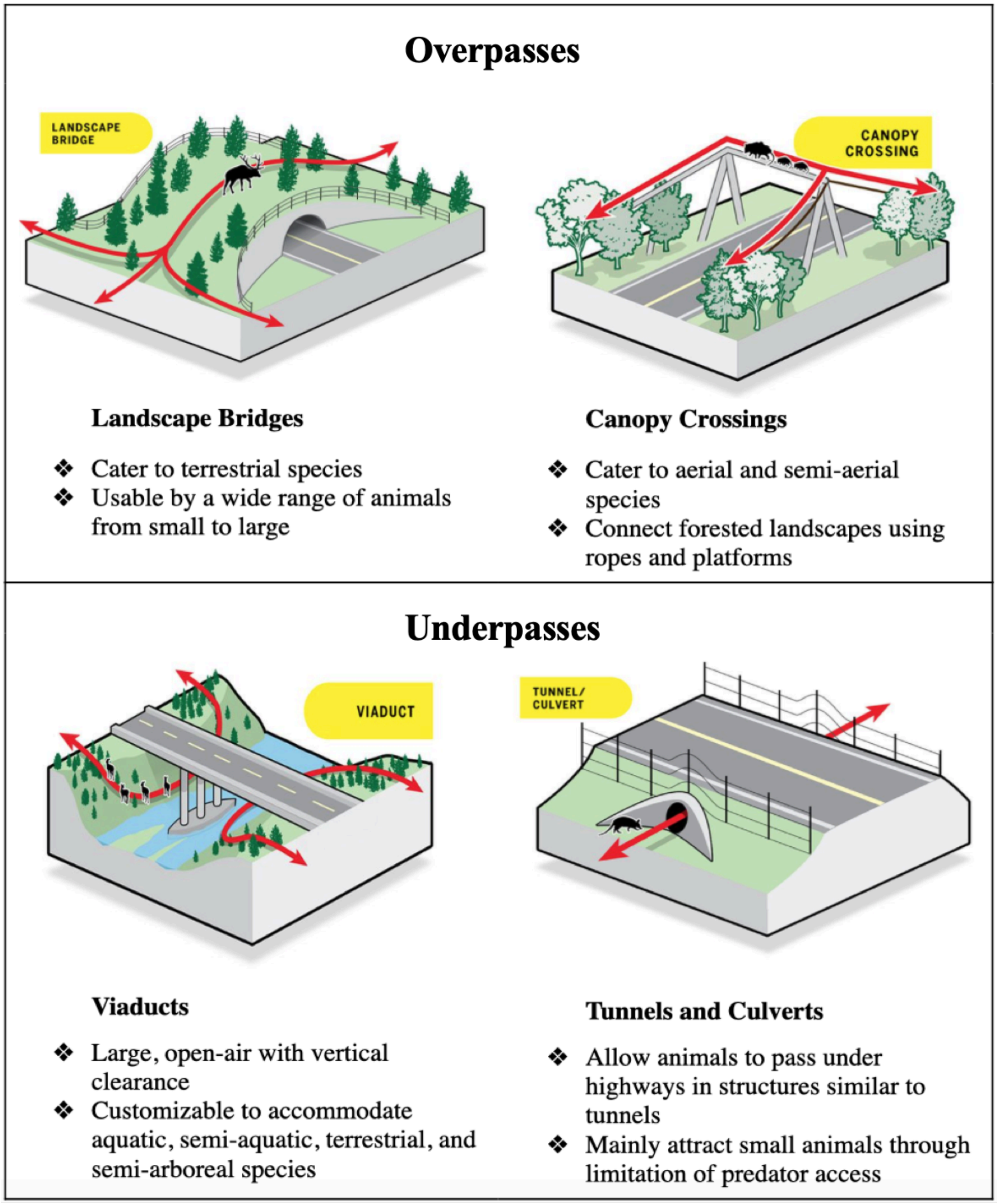


Figure 3: Attributes of Various Crossing Designs [8].

Additionally, all crossings work best when fencing or walls are incorporated to guide the animals towards the corridor [8]. Fences can vary in size; however, all should include components of both man-made infrastructure and the natural environment. The natural barrier should be the first defense to direct animals away from corridor edges, followed by a man-made metal or wire fence (Figure 4).

The natural barrier can be made by using earth berms, dense vegetation, or a combination of both. A vegetative fence should be of local species and be dense and tall enough for the types of animals present. On average, these fences are typically 2.4 meters (8 feet) in height. Natural fences can also help to reduce light and noise penetration that is caused by vehicles while also keeping the animals safe [7]. Although wire or metal fencing is more versatile, it is also more vulnerable to damage caused by the weather and motor vehicles. Fencing can also develop holes that animals are quick to find and take advantage of, making them less effective. This is why it is important to have a combination of natural and man-made barriers.

Figure 4: Calamondin Shrub Barrier to Aid in Deterring Animals along Hwy 1.

Gaining an understanding of the project area's specific features is an important step towards creating the appropriate wildlife crossing design; topography, climate, local species, and material selection play a large role in designing the proper structure. Topography can be categorized four different ways: level, sloped, below-grade, and raised. The type of crossing to be implemented should take advantage of the existing land conditions. For example, if a highway is located in a valley that disconnects terrestrial species, it would make the most sense to design an overpass that connects the two higher points on either side of the highway rather than an underpass (Figure 5). This allows for the structure to blend more seamlessly into the surrounding environment, inviting animals to cross. Because animals are more likely to use a structure that does not appear foreign to them, it is important to populate the crossing with native plants that will, over time, grow and develop into a direct extension of the habitats that are being connected [9]. In addition, mitigating the effects of human activity, such as light and sound pollution of vehicles on the highway, can make the crossing more appealing [9].

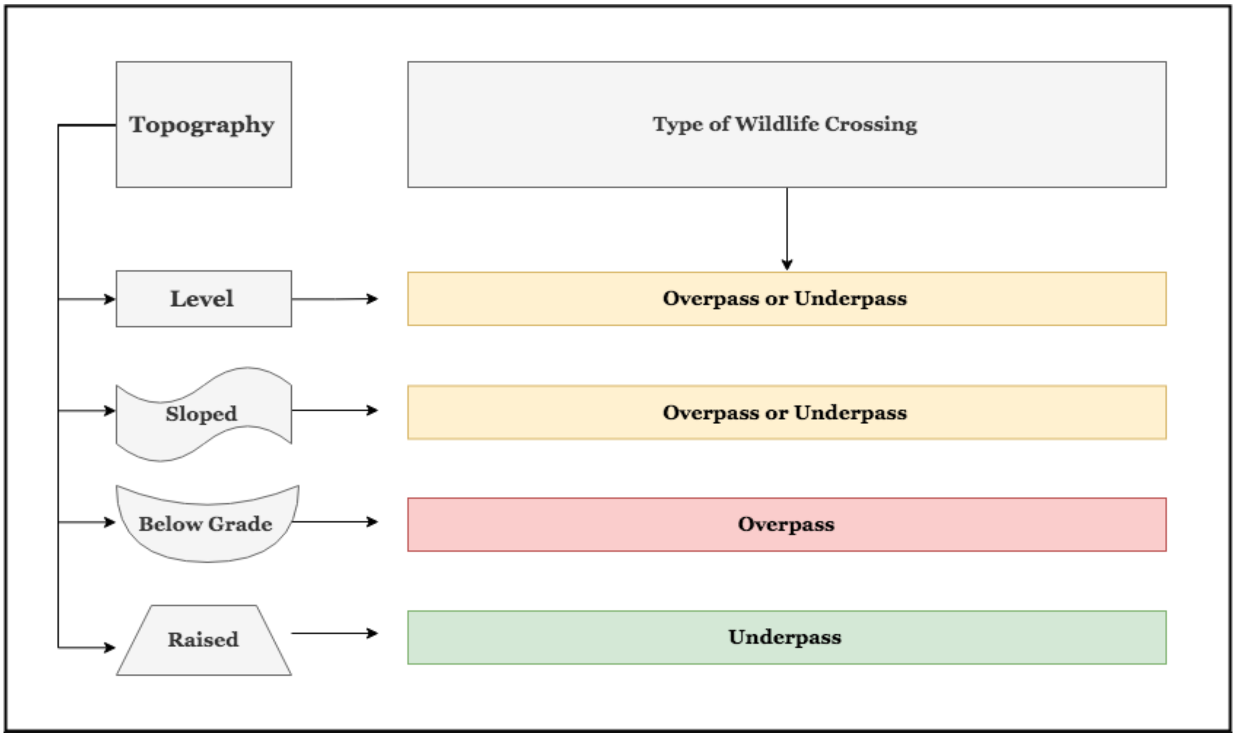


Figure 5: Topography vs. Crossing Type Matrix (Adapted from [7]).

Another consideration for the construction design and material selection is climate. Batipa Peninsula is a varied environment: at the waterline it has dense mangrove forests, teak forests at higher elevations, and wild jungles that serve as a wildlife preserve at the highest elevations. Batipa's tropical climate is extremely hot and humid year-round. The temperatures remain on average between 29 and 32°C (70 and 90°F) and the humidity remains within 5% of a 95% humidity throughout the year [31]. However, the amount of rainfall varies depending on the season. May through November is considered the wet season, where David receives upwards of 400 millimeters (12 inches) of rainfall per month. Whereas in the dry season, December through April, David receives as little as 19.3 millimeters (0.8 inches) in a given month (Figure 6) [32].

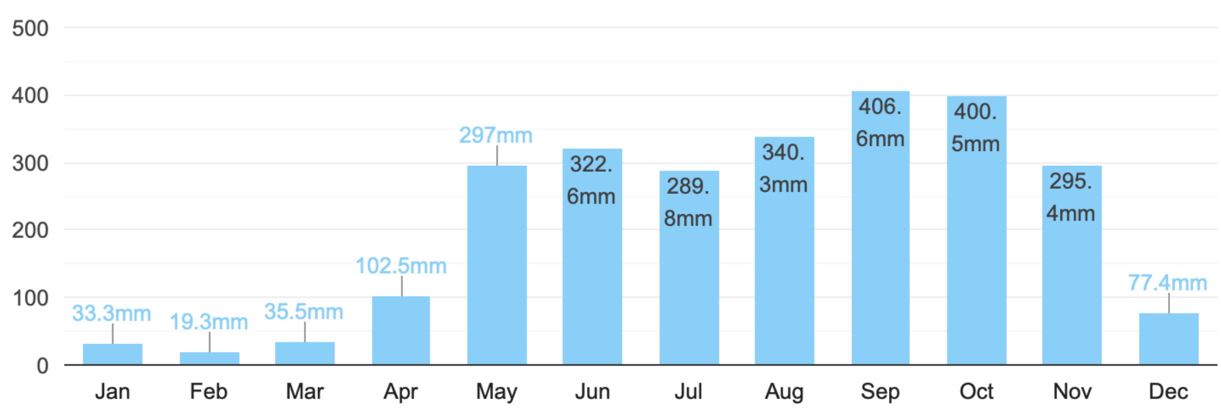


Figure 6: Monthly Average Rainfall in David, Panama [32].

The frequent and intense rain events that occur during the rainy season are very beneficial to the vegetation of Batipa; however, deforestation of land for human use exposes soil that was once protected by the forest canopy. Activities such as cattle ranching and teak forestry create exposed soil that falls victim to erosion and landslides. Soil from the tops of mountains and hills is washed into rivers and the ocean leaving the land bare and unable to be utilized for future agricultural uses [33]. The main strategy currently being implemented to mitigate soil loss from erosion in Batipa is the use of plant species to fortify the soil. Vetiver is a species that has been used worldwide as an effective, low-cost, and natural erosion control measure (Figure 7).

Figure 7: Vetiver Planted in Batipa to Reduce Erosion Effects.

The roots of vetiver can grow as deep as 3 meters (9.8 feet) into the soil, which helps to stabilize slopes by creating a physical barrier to prevent soil movement. The Department of Highways in Bangkok, Thailand began implementing vetiver along its highways as an erosion control method in 1993. Today, the 6.5 million tillers of vetiver planted in Thailand have had very positive results for the country's highways. They note that planting vetiver in clumps spaced 5-8 centimeters (2-3 inches) apart and in rows not more than 50 centimeters (19 inches) apart is very effective for severe slopes [34].

The heavy rainfall in combination with the extreme humidity not only affects erosion measures, but can also nullify the effectiveness of many materials through corrosion or rotting. This puts significance on finding a material resistant to Batipa's tropical environment. One local material option to be considered is teak, a tree that is abundant in Panama and can flourish in the tropical climate. These trees are extremely resistant to weather conditions and have the ability to combat decay, which makes the treated wood very valuable to Panama's industrial market [35]. This hardwood is highly sought after as a building material for both outdoor furniture, boats, and more; however most of it is exported and used elsewhere so teak is not typically used within Panama itself [36]. The two other main building materials to consider in construction are steel and concrete. Steel is an extremely strong, tough, and ductile material which can be molded into a wide array of designs that cater to various applications. In addition, it is relatively sustainable because 90% of all structural steel used today is recycled. This material is non-combustible, however, it does corrode when in contact with water, so it must be implemented in conjunction with a protective coating. Concrete has a high compressive strength, but lacks tensile strength so it must be reinforced with steel rebar for higher effectiveness. Concrete is water resistant on its own, however, when reinforced with steel it is important that the steel rebar is not exposed to the water because it will corrode. Concrete can be molded into many different shapes depending on its function, however it does face limitations for long spans or tall heights when on its own.

After determining whether to construct an overpass or underpass, the specific structural design will depend on the tendencies and types of wildlife that might use the crossing. For example, an overpass for deer may resemble more of a traditional bridge, while an overpass for monkeys would be more effective as a taller structure that mimics travel by treetop. In an area with a variety of wildlife, it is important to have diversity in crossing structures to ensure that all animals are being encouraged to utilize the corridors. The BFI has been working towards this as exemplified by their six completed monkey bridges and their current work in developing existing underpasses into wildlife viaducts by populating the surrounding area with native plant species to encourage a range of animals to pass through (Figure 8).

Figure 8: Canopy Crossing and Viaduct Bypassing Highway 1.

It is very important to have continuity of native soils, plants, and shrubs from the neighboring environments. This means that the soil on the crossing must be deep enough to support a variety of vegetation, from trees and shrubs to different types of grasses that imitate the complexity of a natural forested area.

2.4 Case Studies

All over the world, animal crossings are being constructed to help decrease the number of animal casualties from motor vehicle accidents in addition to preserving habitat permeability and encouraging natural wildlife migrations. The following section highlights three areas with wildlife crossings that have proven to be successful in their location at reducing collisions between animals and motor vehicles. The success of these structures can be credited to understanding the animals that would use the crossings, designing the structures based on the preferences of the wildlife, and observing the use and misuse of the structures after implementation. Observation of the structures after construction is route for the design and application of new crossings that are better utilized and more effective.

Banff, Alberta, Canada

One area for model animal crossings is Banff National Park in Alberta, Canada home to more than 400 species varying in size from grizzly bears and moose to pygmy shrew [16]. The first of over 40 animal crossings was an overpass constructed in 1997 across the Trans-Canada Highway. Since then, five additional overpasses have been constructed in addition to 38 small underpasses. Additional crossings are going through design and construction processes. Parks Canada Agency has documented over 10,000 safe animal crossings at the most recently constructed wildlife overpass which was erected in 201 (Figure 9) [37]. Between 1996 and 2014, over 152,000 crossings by 11 large mammal species have been detected on wildlife overpasses in Banff [38].
An important design factor for animal crossings is the material in which it is covered. In Banff, all overpasses are covered in shrubbery. Scientists observing the use of the structures in Banff found that grizzly bears, elk, deer, and moose prefer big, open structures covered in grass and small shrubs. They also found that black bears and cougars, which live in tall-tree forests, prefer a more covered and hidden route. Wildlife Research Scientist Anthony Clevenger said that the animal preferences "*informed the landscaping on the Banff crossings. On one side we would plant trees and shrubs, and on the other side have areas that are open, planted with grass*" in order to accommodate the variety of wildlife that could use the crossing [28].

Figure 9: Wildlife Overpass in Banff National Park (Alberta, Canada) [37].

Banff National Park is still undergoing the construction and design of new structures that are to be implemented in the park. The success of the wildlife crossings is shown not only in the decrease in animal mortality due to the highway, but also in a social movement. The wildlife crossings have sparked interest across the world for implementation and animal habitat rehabilitation. In addition to the wildlife that inhabits this area, approximately 3.5 million people visit Banff every year, and approximately 4.5 million people commute on the Trans-Canada highway. The wildlife crossings have made it easier for the diverse range of wildlife and large population of tourists visiting the park to more easily and safely coexist [22]. A study completed over a 34-year period from 1981 to 2014 analyzed the number of animal road fatalities on an 84-kilometer (52-mile) stretch of the Trans-Canada Highway in Banff National Park. They found that the number of mortalities decreased significantly after the implementation of the wildlife crossings. The wildlife with the most frequent number of fatalities, elk, had a mortality reduction of 83%. Sheep mortalities were reduced by 96%. Other animals, like wolves, which were observed to not utilize the crossings as frequently as other animals [38], did not follow this same trend (Figure 10) [39].

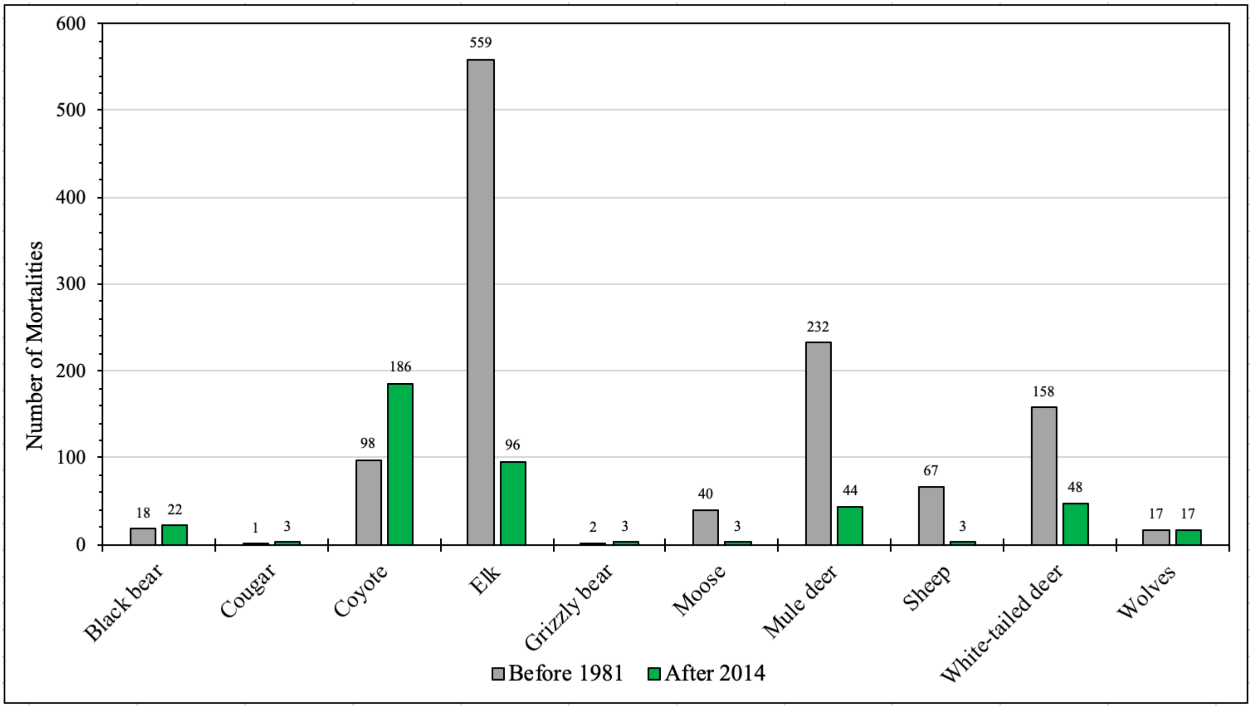


Figure 10: Wildlife Mortalities in Banff before 1981 and after 2014 (adapted using data from [39]).

Not only is the reduction in animal-vehicle collisions beneficial to animals, but also to drivers and park officials. An article from National Geographic examining the long-term benefits of the animal crossings in Banff reported that vehicle-elk collisions cost an average of $25,319 when taking into consideration not only vehicle repairs, but also the disposal of the carcass and other expenses by the park [28]. Comparing this to the amount of collisions from the previous study, this could be an annual difference of over $11 million.

The continued research completed on the wildlife crossings in Banff National Park demonstrate the importance of mitigating habitat fragmentation. They help to prevent motor vehicle accidents, act as a demonstration site for other ecological preservation projects in Canada and across the world, and allow for near continuous natural flow of populations and species through areas that were once remote and are now disturbed by human activities [28].

Ecoduct de Woeste Hoeve, Netherlands

The major consideration for a crossing developed in The Netherlands was ensuring that the bridge was adequately sized to encourage all types of wildlife to use it. The A50, a major highway that cuts through The Veluwezoom National Park, was the main reason for the construction of the Woeste Hoeve Ecoduct in 1988 (Figure 11). The purpose of the wildlife overpass was to reunite disconnected herds that used to roam freely in the land before the motorway. The large trucks commuting on the highway made it especially dangerous for animals to try and cross because traffic is often backed-up [40]. After the Woeste Hoeve was built, it was observed and monitored by researchers to understand how the crossing was being utilized by animals. The Woeste Hoeve was specifically designed to be located where it would be close to many big herds such as badgers, deer, rabbits, foxes, wild boar, and more.

Figure 11: Aerial Image of the Ecoduct de Woeste Hoeve (The Netherlands) [41].

The dimensions are very important when designing a wildlife crossing bridge. Researchers found that if the bridge was 50 meters (164 feet) or larger, it would be used by a wide variety of animals, and a local study of a much smaller bridge with a width of 20 meters (65.6 feet) showed that it was undoubtedly used by fewer species of animals [41]. In the same study, observation showed that many animals prefer to use the center of a crossing, deer were even observed to keep a distance of 3.5 meters (11.5 feet) from the edge of a crossing [41]. This is a common tendency for many animals that use the crossings.

Not only are wildlife crossings developed to protect animals from roadways, they also serve to protect drivers from wildlife that try to cross the road. Many overpass crossings have traditional fences to keep animals in, but the Woeste Hoeve took a different design approach. The bridge was constructed with a slight concave shape to encourage the animals to stay closer to the middle and there are also 1.5-meter (5-foot) tall earth walls along the sides of the overpass to further ensure no animals stray too close to the edge [41].

Compton Rd, Queensland, Australia

Running east and west through the Karawatha Forest and Kuraby Bushlands is Compton Road, a major roadway in Brisbane, Australia. In 2003, when plans came out to expand the highway from two lanes to four, the Brisbane City Council decided that they were going to construct a wildlife overpass to help reduce the number of animal casualties. Compton Road already has many other wildlife passes including an underpass for larger animals, culverts for small animals, and rope ladders for possums [42]. A number of different wildlife crossings were constructed on Crompton Road along a section of 1.3 kilometers (0.8 miles) to ensure that all species would be able to cross safely (Figure 12).

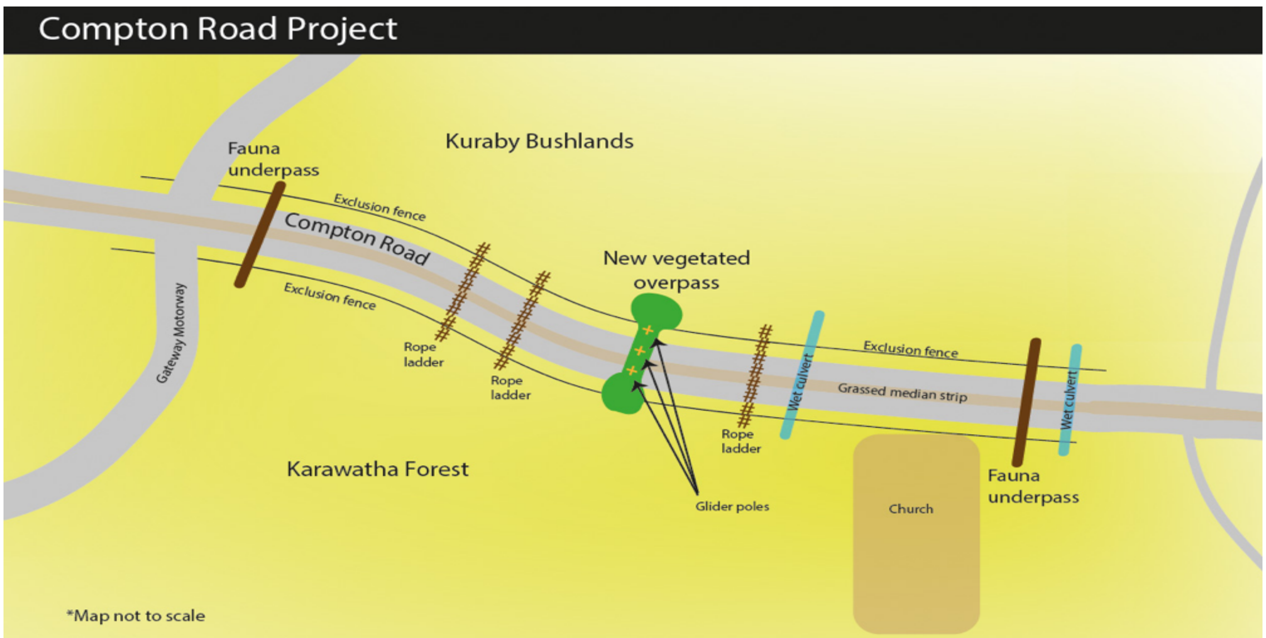


Figure 12: Diagram of Wildlife Crossings on Compton Road (Queensland, Australia) *[42].*

After only a few months post-construction, animals of all species were using the crossings. Cameras and sand paths were set up in the tunnels and along the bridge so that researchers could track the number of animals using the crossings. One of the main things that helped make the crossing so popular was that it replicated the forest on both sides of the structure (Figure 13). There were large trees and small shrubs covering it so that animals felt like it was just an extension of the forest. Once the trees got bigger, many people noticed that birds started to use the crossings a lot more than expected. This is because smaller birds will not fly across 120 meters (394 feet) of busy traffic, most just fly about 2 meters (6.6 feet) from bush to bush. This is also the same with bats; they previously would only fly up along the road, but now with the crossing, they fly frequently from side to side [42].

Figure 13: Wildlife Crossing Overpass on Compton Road (Queensland, Australia) *[42].*

Before the wildlife crossing was built, millions of dollars were being lost to vehicle collisions with due to animals attempting to cross the roadway. Before the construction of the bridge around 14 wallabies and three koalas were killed on Compton Road per year. Now, ten years after the construction of the overpass, only three wallabies have been killed by motor vehicles, a significant improvement from what it once was [42].

2.5 Summary

A promising solution to mitigating threats to biodiversity and gene flow due to habitat fragmentation from transportation infrastructure is wildlife crossings. The Pan-American Highway cuts through the Batipa Wildlife Corridor and is threatening to permanently disrupt the natural habitats that occupied the area long before the highway's construction. Panama has a diverse array of flora and fauna species, some of which are endangered. As humans depend on the ecology of undeveloped and remote areas for technological, medical, and societal advancements, it is crucial to implement strategies to mitigate disruption to the natural systems.

There are many design parameters to balance in order to make wildlife crossings practical and effective for the ecosystem in the specific area. Research must be completed prior to designing the crossing to determine the types of animals present and to observe their interactions with the current transportation system and with each other. The topography, climate, and local vegetation must also be considered in order to create a structure that has continuity with the natural surrounding environment. The main types of wildlife crossings include overpasses and underpasses - all of varying size, shape, material, and location. Examining the successes and pitfalls of previous crossings will allow for a holistic approach to creating a pragmatic and functional design for the Batipa Corridor and the Inter-American Highway wildlife crossing structure.

3.0 Methodology

The goal of this project was to design a biological crossing that is appropriate to the wildlife and environmental specifications of Highway 1 on the Batipa Peninsula in Panama. The design includes material selection for the structure based on compatibility with the local environment, accessibility to the building materials, and local familiarity of use, in addition to a complete analysis of the structural components of the crossing.

The project deliverable is a complete wildlife crossing design in AutoCAD and Revit provided to Universidad Tecnológica Oteima. This design is to be used to pitch the project to potential sponsors for funding and to the Panamanian government for permission to move forward with construction. The project team progressed through the following objectives:

Objective 1: Identify Parameters of Design Through Data Collection
Objective 2: Create and Refine Crossing Design
Objective 3: Deliver Final Design

In order to begin the design process, travel from Panama City to the project site on Batipa peninsula was necessary to survey the project site and take measurements. Through face-to-face discussion with the sponsor and measurement processes, the information needed to properly diagram the wildlife crossing remotely from Panama City was obtained.

The two main contacts, Dr. Francisco Ugel of UTO and BFI's Coordinator Edmundo Gonzalez, were met with to gain information on their vision of the crossing before the design process began. The stakeholders gave qualitative data on what the crossing should look like, material suggestions, placement relative to Highway 1, and what types of animals to target. In addition, through discussion, a definitive material selection was made based on feasibility and effectiveness. The climate patterns of the area also played a role in this decision because a material was needed that would be durable enough to withstand harsh weather conditions, especially in the rainy season. The stakeholders also provided context on previous work to reference and studies done on biological connectivity in the area including monkey bridges and developing ecoducts.

The area of study, Highway 1, is a modern four-lane highway with jersey barriers down the center. Before beginning to design a crossing for this area, measurements were taken. In addition to being at least 5.5 meters (18 feet) off the ground to accommodate traffic, the width and length of the crossing had to be determined. The following values were obtained utilizing topographical imagery and basic calculations: total width of Highway 1, distance from each edge to center barrier, and width of jersey barriers. In order to obtain these measurements, the land was first examined using Google Earth and from topographical information provided by Universidad Tecnológica Oteima. Additionally, physical land surveys were conducted by driving along Highway 1, stopping in relevant areas to observe the land and road, and photographing areas of concern and potential locations for the crossing. The documentation of the land gave information that helped determine the best location for the proposed design based on position relative to natural habitats, other developed crossings, and highway infrastructure.

The target wildlife and their natural habitats were a criterion of the initial design. In order to grasp an understanding of which species are present in the area and to guarantee that they were captured within the proposal, an extensive catalog of fauna was created. Previously, the BFI completed many studies documenting animal species present in Batipa by the use of motion-activated camera traps. By utilizing and compiling information from these studies and by discussing findings with stakeholders who have firsthand experience with the nature reserve, a list of the most prevalent animals was created. The list was then supplemented using information from online resources such as the Encyclopedia of Life and the Smithsonian Tropical Research Institute animal database to gain a better understanding of the animals' behaviors and characteristics. The following information regarding animals was collected:

- Animal Scientific Name
- Common Name (in both Spanish and English)
- Typical Weight
- Typical Group Size (Solitary, Pack, etc.)
- Travel Preference (Terrestrial, Arboreal, etc.)
- Comments

Similarly, the plant species of the area were taken into consideration when creating the design to ensure continuity of vegetation across the corridor. This affected decisions regarding the width of the corridor as well as the soil composition. The surrounding landscape also determined what materials made an effective sound and light barrier. Studies provided by the BFI along with data from the Encyclopedia of Life and the Smithsonian Tropical Research Institute were utilized to develop a list of noteworthy species supplemented with specific characteristics relevant to both the aesthetic design and functionality of the crossing. The following information regarding vegetation was collected:

- Vegetation Species Scientific Name
- Common Name (in both Spanish and English)
- Type of Vegetation
- Size (Root Depth, Height)
- Additional Comments

In addition to flora and fauna considerations, smaller pieces of infrastructure were developed in the initial design of the crossing. A fence was designed using a combination of traditional fencing material and plants in order to funnel animals towards the bridge. Through collection of all of this data, a correctly scaled design was produced. Additionally, the land surveys around the highway gave insight on the soil conditions, native vegetation, and typical wildlife. Observing the soil helped to determine what type of foundation was required for the crossing and the landscape to ensure that the crossing's vegetation flowed effortlessly into the natural surrounding area. Along the road were various fences, guard rails, and vegetated barriers that were examined for potential use as a funnel for the crossing or for fencing along its edge. Once all of the necessary data was collected the next step was creation of initial designs, consultation with sponsor, and refinement of the model (Objective 2). Using the information gathered in Objective 1, a list of applicable design criteria was created that would influence the initial design.

The initial design was intended to serve solely as a visual representation of the crossing to show to stakeholders and gain feedback on how they would like the team to proceed regarding proposed location and physical design concerns. Using AutoCAD, a rough outline of the crossing with proposed location, aesthetic design, and size was created and presented to Francisco Ugel and Edmundo Gonzalez. Based on the feedback, the design was further developed to address the stakeholder's desires, needs, and concerns. This visual design was then transformed into a well-developed engineering structure through the use of codes, design criterion, and calculations. In order to ensure that the designed crossing could withstand the forces that would be acting on it, both internally and externally, a number of structural calculations were performed. Throughout the calculation process, various sources were utilized for design and classification purposes. These sources were referenced for standards of design, equations, codes, and specific design values (Table 1).

Table 1: Design References for Various Structural Considerations.

Reference Manual, Standard, Specifications	Design Aspect
AASHTO LRFD Bridge Construction Specifications (Sections 8 and 9), Fourth Edition [43], [44]	• Concrete Structure Design • Reinforced Concrete and Steel Construction
AASHTO LRFD Bridge Design Specifications, Eighth Edition [45]	• Load Combinations • Structural Analysis • Foundation Design
ASCE 7-10 (Guide to Wind Loads and Guide to Seismic Loads) [46], [47], [48], [49]	• Design Wind Loads • Design Seismic Loads
"Reglamento de Diseño Estructural para la República de Panamá" REP-2003 ("Structural Design Code for the Republic of Panama") [50]	• Seismic Zoning • Design Seismic Loads
Structural Steel Designers' Handbook: AISC, AASHTO, AISI, ASTM, AREMA, and ASCE-07 Design Standards, Fifth Edition [51]	• Arch Bridge Design • Steel Design
USDOT FHWA Geotechnical Aspects of Pavements Reference Manual [52]	• Soil Classification and Loading • Geotechnical Considerations
USDOT FHWA Reference Manual for Load and Resistance Factor Design (LRFD) for Highway Bridge Superstructures [53]	• Bridge Structural Analysis • Bridge Design and Location
USDOT FHWA Technical Manual for Construction and Design of Road Tunnels - Civil Elements [54]	• Tunnel Design • Geotechnical Considerations

Because the calculations performed were completed primarily using US reference manuals, the units in the following chapters are primarily represented in the British System. A conversion table for British System units and a conversion table from British to Metric System units has been provided (Table 2, Table 3).

Table 2: Conversion Table from British System to Metric System.

Unit of Measure	British System equal to	Metric System
Force	1 kip	4448.22 N
Pressure	1 ksf	4788.03 N/m^2
Density	1 kcf	157.087 kN/m^3
Length	1 mile	1,609.34 m
	3.2808 ft	1 m
	1 in	2.54 cm
Area	10.7639 ft^2	1 m^2
	1 in^2	6.4516 cm^2
Volume	1 in^3	16.3871 cm^3
	35.3147 ft^3	1 m^3
Velocity	1 mph	1.6093 kph
Acceleration	32.2 ft/s^2	9.81 m/s^2
Mass	2.2046 lbm	1 kg
	1 slug	14.5939 kg

Table 3: British System Conversion Table.

Unit of Measure	British System equal to	British System
Force	1 kip	1000 lbf
	1 lbf	1 slug ft/s^2
	1 lbf	32.1741 lbm ft/s^2
	1 kip	3217.41 lbm ft/s^2
Pressure	1 ksf	1000 psf
Density	1 kcf	1000 pcf, lb/ft^3
Length	1 mile	5280 ft
	1 ft	12 in
Mass	1 slug	32.1741 lbm

In order to address variable loading conditions, references tailored to these specifications were used. In conjunction with the various references that spoke to specific considerations, the overarching design method used was Load and Resistance Factor Design (LRFD). LRFD is a limit state design method used in structural engineering that ensures a structure is proportioned correctly so as to accommodate all forces likely to act upon it during its use. This design method accounts for variability in load and resistance which provides a uniform level of safety and resistance. For bridge design, The American Association of State Highway and Transportation Officials (AASHTO) published LRFD Bridge Design Specifications, which establishes the framework utilized on this project for load combinations and basic design methods. This manual was a key component in ensuring that the design developed satisfied all limit states.

In addition to referencing literature and performing hand calculations, RISA-3D, a structural analysis software, was utilized. After creating models of the crossing's structural members within the software, loading conditions were applied to the structural configuration in the x-, y-, and z-directions to simulate the various load combinations that must be considered for design. After inputting the data, RISA-3D analyzed the effects of the loads and determined the moment and shear values that were ultimately used to confirm or adjust sizing of the structural members. By utilizing this software, the crossing design was ensured to be safe within the requirements established by the load effects. The process for evaluating the loads, loading factors, loading combinations, and structural member design is outlined as follows:

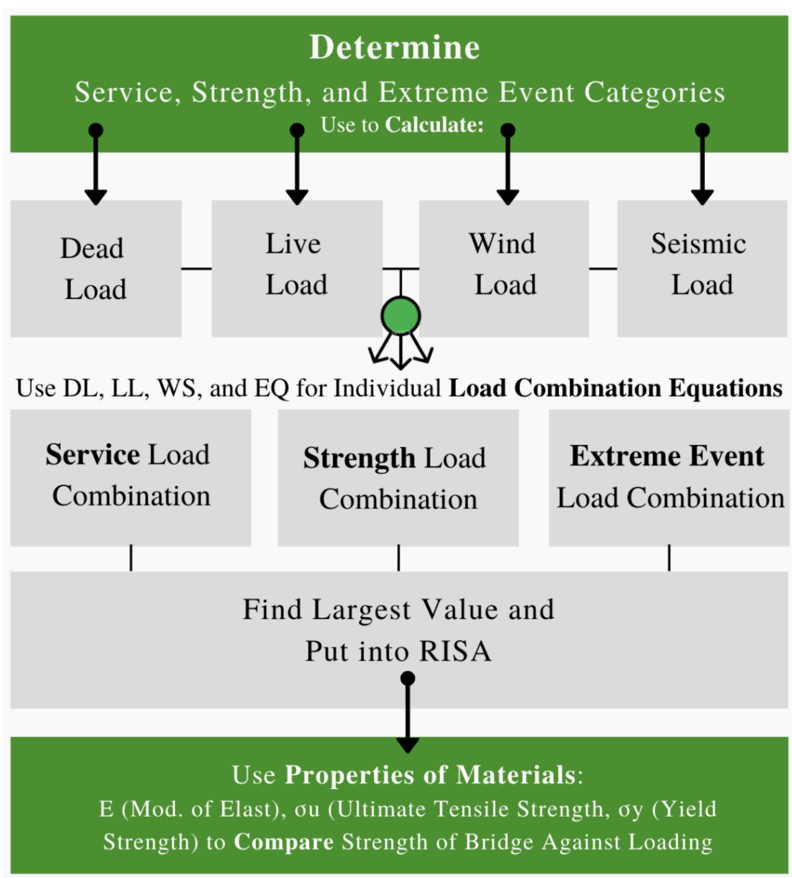


Figure 14: Load Analysis Process Diagram.

The analysis of the crossing began with solidifying dimensions for the structure itself. Using the highway measurements and topographical specifications found in Objective 1, the length and width of the crossing were determined. In addition, the tunnel design (number of tunnels and their width, length, and height) and arch slab specifications were set. Based on the intended uses of the bridge, existing conditions of the topography, and construction materials to be used, the LRFD loading design must satisfy the following different state limits set forth by US Department of Transportation Federal Highway Association (USDOT FHWA) in their LRFD Reference Manual for all loading combinations: service, strength, and extreme event (Table 4, Table 5, and Table 6). The limit states guided the load combinations that were used to correctly design the structural members of the crossing.

Table 4: Classification of Service Limit States (adapted from Table 3.10.1.3.6-1 in [45]).

Service State	Design Aspects
Service I	Deflection control, crack control in reinforced concrete, controls compression in prestressed concrete
Service II	Only applies to steel structures
Service III	Tension and crack control in prestressed concrete
Service IV	Only applies to substructures

Table 5: Classification of Strength Limit States (adapted from Table 3.10.1.2.7-1 in [45]).

Strength State	Design Aspects
Strength I	Typical bridge, no wind load
Strength II	Special permit vehicles, no wind load
Strength III	Wind speeds exceeding 55 mph, no live load
Strength IV	Emphasized dead loads, typically for long span bridges, no wind load
Strength V	Vehicular use, wind load on structure and live load

Table 6: Classification of Extreme Event Limit States (adapted from Table 3.10.1.4.4-1 in [45]).

Extreme Event State	Design Aspects
Extreme Event I	Earthquake events
Extreme Event II	Blast loading, ice flow impact, vehicular collision events

The crossing design was then evaluated for different loading conditions to ensure that it would withstand the forces that would be put on it over time. The following forces guided the analysis of the crossing design:

Table 7: Loading Conditions to be Considered and Calculated.

Load	Load Description	Standard, Manual, or Reference Guide
Dead Loads (DL)	Structural components of crossing, soil backfill, and vegetation on crossing	AASHTO LRFD Bridge Design Specifications Section 3.5.1
Live Load (LL)	Wildlife utilizing crossing	AASHTO LRFD Pedestrian Bridge Design Specifications Section 3.1, 3.2
Wind Load on Structure (WS)	Horizontal wind pressure force on structure	ASCE 7-10 Guide to Wind Loads
Earthquake Load (EQ)	Seismic forces due to Earthquake	ASCE 7-10 Guide to Seismic Loads, Structural Design Code for the Republic of Panama

After dimensioning the crossing, calculations were performed to determine the mass of construction materials (concrete and steel rebar) as well as the soil backfill. These dead loads were determined using AASHTO design criteria and the following basic equation multiplying volume by unit weight:

$$DL = V \times \lambda$$

Where:

DL = Dead load force (kips)
V = Volume (ft^3)
λ = Unit weight (kcf)

In order to determine the force placed on the structure by the compact soil, the soil first had to be classified. Using Tables 5-9 from USDOT FHWA Geotechnical Reference Manual, the soil type and unit weight were established. The soil unit weight (in kips/ft^3) was then multiplied by the width of the crossing and the depth of the soil to find the area of packed soil acting on a cross section of the crossing and distributed force it applies on the structure.

The dead loads exerted by the structure's self-weight were found using the same methods as used for the soil. The unit weight of concrete (in kips/ft) was found using Table 3.5.1-1 of AASHTO's LRFD Bridge Design Specifications Reference Manual. Section 8 of AASHTO Bridge Design Specifications states that the unit weight of reinforced concrete can be taken as 0.005 kcf larger than the unit weight of the concrete. The unit weight value was multiplied by the width of the crossing and the thickness of the concrete slab. This gave the total force exerted on the crossing by the concrete.[1]

[1] The material dimensions were arbitrarily chosen at this stage, they were re-sized based on the RISA analysis.

The only live loads to be calculated for the crossing were the animals that would be utilizing the structure. In order to estimate the pressure force exerted by animals, the catalog of fauna with information on average weight and group travel tendencies was used. The equation for calculating the live load force is similar to that for dead loads:

$$LL = \frac{(SA \times P)}{1000}$$

Where:

LL = Live load force (kips)
SA = Surface area of crossing (ft^2)
P = Pressure exerted by animals (psf)

The wind loads were determined using a combination of local topography information, the service and strength limit states and the ASCE 7-10 Guide to Wind Loads. The governing equation from the ASCE Guide to Wind Loads used to calculate the horizontal force exerted by the wind on the crossing was as follows:

$$q = 0.00256\, K_z K_{zt} K_d V^2$$

Where:

q = Effective velocity pressure (psf)
K_z = Exposure Velocity
K_{zt} = Topographical Factor
K_d = Directionality Factor
V = Basic Wind Speed (mph)

The effective velocity pressure (q) was then multiplied by the vertical surface area perpendicular to the wind velocity to calculate the Wind Loading pressure force (WS):

$$WS = \left(\frac{q \times A}{1000}\right)$$

Where:

WS = Wind Load Force (kips)
q = Effective velocity pressure (psf)
A = Surface area perpendicular to wind pressure (ft^2)

Using the height of the structure and Table 27.1-1 from The Guide to Wind Loads, the exposure velocity (K_z) was found. Next, the directionality factor (K_d) based on the structure type was found using table 26.1-1 from The Guide to Wind Loads. Based on the state limit classifications and topographic conditions upwind of the crossing, the 3-second gust wind speed was determined using a table from The Guide to Wind Loads (Figure 15). All of these values were plugged in to the governing equation in order to get the effective velocity pressure.

Load Combination	3-Second Gust Wind Speed (mph), *V*
Strength III	Wind speed taken from Figure 3.8.1.1.2-1
Strength V	80
Service I	70
Service IV	0.75 of the speed used for the Strength III limit state

Figure 15: Wind Speed (V) Based on Load Combination [49].

In order to make certain that the crossing could hold up against seismic activity, the potential seismic loads were calculated using the ASCE 7-10 Guide to Seismic Loads and the Structural Design Code for The Republic of Panama. The governing equation for determining the Seismic Load was as follows:

$$EQ = \frac{(m \times PGA)}{3217.41}$$

Where:

EQ = Seismic Load (kips)
m = Mass of crossing structure (lbm)
PGA = Peak ground acceleration (ft/s^2)

The mass of the structure can be calculated from its dead load force:

$$m = \frac{F}{a} \times 3217.41$$

Where:

m = mass of structure (lbm)
F = DL (kips)
a = acceleration due to gravity (ft/s^2)

The PGA value to be applied to the calculations was determined using a seismic threat map from the Structural Design Code for the Republic of Panama (Figure 16):

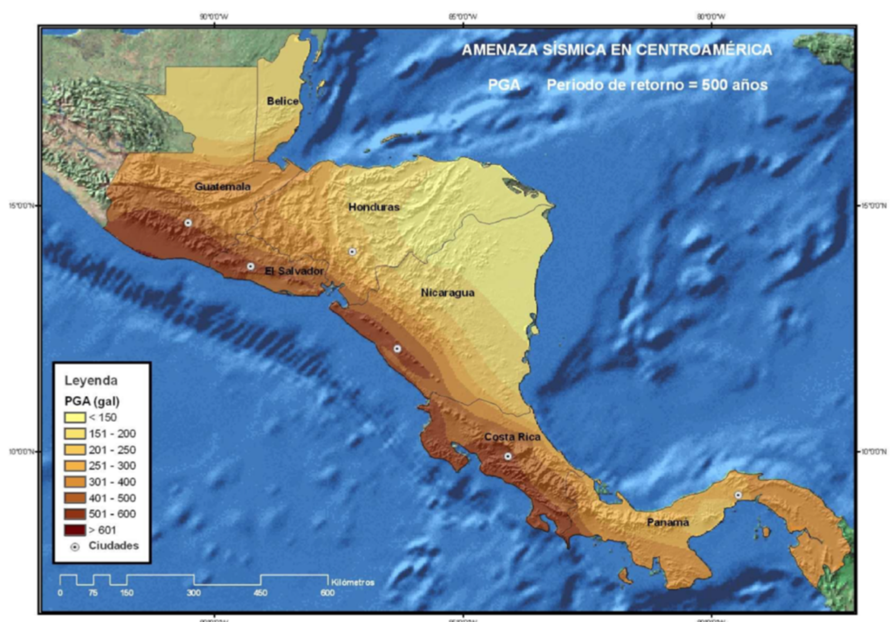


Figure 16: Peak Ground Acceleration Values (in gal) for Central America [50].

Once the values for DL, LL, WS, and EQ (in kips) were calculated, the values were multiplied by load factors and summed together. The combination of load factors depended on the strength, service, and extreme event limit states. Each applicable load factor combination scenario was calculated, the equation that produced the largest force acted as the governing equation for design (Table 8).

Table 8: Load Combinations and Factors Based on Limit States (adapted from Table 3.4.1-1 in [45]).

Load Combination	Component Dead Loads (DL)	Live load (LL)	Wind load on structure (WS)	Earthquake load (EQ)
Strength I	1.25	1.75	-	-
Strength II	1.25	1.35	-	-
Strength III	1.25	-	-	-
Strength IV	1.25	-	-	-
Strength V	1.25	1.35	1.00	-
Extreme Event I	1.25	0.50	-	1.00
Extreme Event II	1.25	0.50	-	-
Service I	1.00	1.00	1.00	-
Service II	1.00	1.30	-	-
Service III	1.00	0.80	-	-
Service IV	1.00	-	-	-

The loads with their respective load factors determined from Table 8 were then utilized in the RISA-3D software. The loads enacted on the structure in RISA produced minimum and maximum values for shear, moment, torque, axial forces. Using the properties of the reinforced concrete, such as yield strength and modulus of elasticity, the bridge was tested to determine if its strength was sufficient to withstand the imposed loads, shear forces, and moments. The steel reinforcement sizing was adjusted in order to safely endure the loading forces acting on it. Using conservative loading conditions, concrete and steel design, and RISA software, the crossing was designed to be able to withstand the dead, live, wind, and seismic forces that would affect the bridge throughout its lifetime.

Once the crossing was properly dimensioned, it was visually represented using Google Earth, AutoCAD, and AutoDesk Revit. In order to first understand the proposed location, an aerial view image was created by super imposing images on Google Earth at the proposed location. Next, the AutoCAD drawings served to give a 2D depiction of the crossing with material cross-sections and key dimension values. In order to give a quality portrayal, various views were made including the crossing's placement on the highway, highway view, crossing view, and close-up of the reinforced concrete arches. After completing the AutoCAD design, a 3D model of the crossing was made using AutoDesk REVIT. This 3D model served to give a more realistic view of the crossing with the surrounding area and vegetation included. Through the various portrayals of the crossing, structural, geotechnical, and construction details were illustrated based on both the needs and wants of stakeholders, and engineering standards of design. The entire bridge design, as well as small details, were depicted with dimensions and materials in order to give an all-encompassing illustration of the proposed design as a final deliverable.

4.0 Results

In this chapter, the results are presented including preliminary site evaluation data and visuals as well as design processes. The complete set of calculated values and dimensions are displayed in the various tables and the final deliverable images are included.

Through discussions with stakeholders and topographical analysis of the area, a greater level of understanding of the current issue was gained and measurements of the highway were obtained. The first step to gaining a holistic understanding of the physical context of the problem was driving along Highway 1. The habitat fragmentation caused by the highway was observed first-hand by the frequently seen roadkill, heavily vegetated surrounding environment, and graffiti. The roadkill indicated the need for the crossing as wildlife were unsuccessfully attempting to cross the jersey barriers from their habitat to the area across the roadway (Figure 19). Along the jersey barriers, the team identified graffiti showing community support for animal safety. The phrase "SOS SALVEN A LOS ANIMALES" ("SOS SAVE THE ANIMALS") was written on multiple stretches of road (Figure 17). The dense forest on either side of the highway further emphasized that the highway was directly dividing two flourishing environments with a plethora of wildlife (Figure 18).

Figure 18: Division of Habitats by Highway.

Figure 17: "SOS SALVEN A LOS ANIMALES" Graffiti.

Figure 19: Roadkill on Highway 1.

Through observing the highway, it was noticed that there were small gaps in the jersey barriers approximately every 2 kilometers (1.24 miles) (Figure 20). This is one area where animals would not have to go over the barriers to cross, but even so, it would be extremely unlikely for an animal to identify the gap in the jersey barrier as a safe place to cross the highway. This is evidenced by the high volume of roadkill. Upon further discussion with stakeholders, it was understood that the gaps were made for human use rather than for animals.

Figure 20: Current Accessibility to Crossing Animals through Jersey Barriers.

Figure 21: Supplementary Wildlife Crossing Developments

The wildlife protection efforts that the BFI has already implemented were also witnessed firsthand. The BFI has established six canopy crossings for monkeys that span from the treetops on either side of Highway 1 (Figure 21). The crossings were supplemented by signs on the highway to make drivers aware of the structure and its purpose. The sign reads: "DISMINUYA LA VELOCIDAD PRESENCIA DE FAUNA" ("REDUCE SPEED PRESENCE OF FAUNA").

Further information was obtained from the stakeholders with long-term personal interaction with the system in order to better comprehend the situation. Coordinator of the BFI, Edmundo Gonzalez provided information on soil conditions, potential natural materials for use on the crossing, and which wildlife species to target.

One of the main concerns of the Batipa region is soil erosion due to heavy rainfall. As the rain runs through the ground, the soil is stripped of vital nutrients, causing it to change from a dark brown color to more orange (Figure 22). Sr. Gonzalez expressed BFI's intense concentration on mitigating the effects that erosion has on the area through the use of conscious agricultural techniques and erosion preventing tactics. In order to make certain that the crossing, once constructed, was not negatively impacting the land's integrity, various strategies were discussed. The method chosen to be implemented on the design was the use of vetiver, a perennial bunchgrass (Figure 23). Vetiver is a natural erosion combatant, as it is a non-invasive species with a dense web of roots that have the ability to penetrate vertically up to 4.5 meters (15 feet), slow down water loss, and trap sediment and debris. It is also utilized commonly for this purpose across the world due to its ability to grow in soils that are normally inhospitable to other plants due to salinity, pH, or drought.

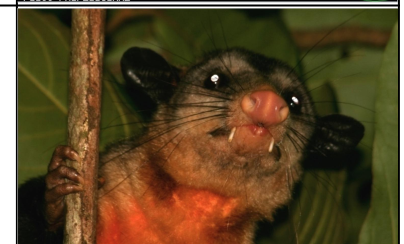
Figure 22: Nutrient Depletion in Soil Represented by Red Coloration.

Figure 23: Vetiver Erosion Control Measures in Batipa.

In addition to suggesting the use of vetiver on the crossing, Edmundo also gave insight on a potential shrub to be used for natural fencing: calamondin. Calamondin, a small thornless citrus tree, was frequently seen while driving along Highway 1 as a barrier between homes and the road. Utilizing this for the crossing as fencing would provide a natural sound and light barrier. It would also be much more inviting for animals compared to the large foreign infrastructure of the cement wall.

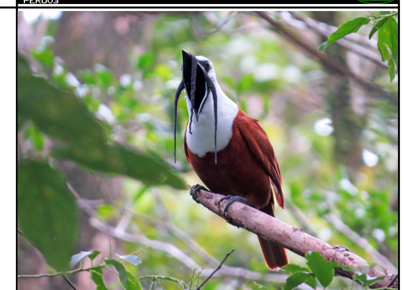
A main concern that was expressed throughout discussion with stakeholders was ensuring that the crossing was developed to target the correct wildlife. Currently, Batipa has a canopy crossing for marsupials, an ecoduct for small terrestrial animals, but nothing for large terrestrial species such as deer, which are abundant in the area. In order to ensure that appropriate wildlife and plants were targeted and utilized for the crossing. The catalog developed in Objective 1 regarding flora and fauna species is as follows:

Catalog of Batipa's Fauna

Scientific name	Common name (Spanish)	English Name	Average Weight	Typical Group Size	Travel Preference	Comments	Picture
Dasyprocta punctata	Ñeque	Agouti	2-3 kg	Travel in pairs of 2, have litters of 1-3	Terrestrial	Most documented species in Batipa	
Didelphis marsupialis	Zarigüeya	Opossum	1 kg	Usually solitary, except during mating season	Arboreal		
Odocoileus virginianus	Venado de cola blanca	White-tailed deer	55 kg	Travel in groups of 2-15	Terrestrial		
Proechimys semispinosus	Rata espinosa	Tome's spiny rat	360 g	Solitary	Terrestrial	Nocturnal	

Scientific name	Common name (Spanish)	English Name	Average Weight	Typical Group Size	Travel Preference	Comments	Picture
Cuniculus paca	Conejo pintado	Lowland paca	7-10 g	Solitary, have litters of 1-3	Terrestrial		
Tayassu pecari	Pecarí barbiblanco/ Saíno	White-lipped peccary	25-40 kg	Herd size typically ~100	Terrestrial	Vulnerable species, decreasing population trend	
Conepatus semistriatus	Mofeta bilistada/ Zorrillo	Striped hog-nosed skunk	1.2- 3.5 kg	Solitary or in groups of two	Terrestrial	Nocturnal	
Nasua narica	Gato solo	White-nosed coati	4 kg	Maintain a social structure of female-bonded groups (called bands) and solitary males	Terrestrial		

Scientific name	Common name (Spanish)	English Name	Average Weight	Typical Group Size	Travel Preference	Comments	Picture
Dasypus novemcinctus	Armadillo de nueve bandas	Nine-banded armadillo	5 kg	Solitary	Terrestrial	Nocturnal	
Puma yagouaroundi)	Yaguarundí/ Tigrillo congo	Jaguarundi	6.9 kg	Solitary	Terrestrial		
Leopardus pardalis	Manigordo/ Ocelote	Ocelot	8-20 kg	Solitary	Terrestrial		
Cebus capucinus	Monos cariblancos	White-faced capuchin monkey	2.9-3.9 kg	Average of 15 in a group	Arboreal		

Scientific name	Common name (Spanish)	English Name	Average Weight	Typical Group Size	Travel Preference	Comments	Picture
Tamandua mexicana	Oso hormiguero	Anteater	4.2 kg	Solitary	Semi-Arboreal		
Puma yagouaroundi	Yaguarundís	Jaguarundi	7 kg	Solitary	Terrestrial		
Procnias tricarunculata	Pájaro campana	Three-wattled bellbird	145-220 g	Solitary unless with mate	Aerial		
Diplomys labilis	Rata espinosa	Panama Spiny Gliding Rat	228g	Alone or with pairs	Semi-Arboreal		

Scientific name	Common name (Spanish)	English Name	Average Weight	Typical Group Size	Travel Preference	Comments	Picture
Leptopogon amaurocephalus	Mosquerito gorrisepia	Sepia Capped Flycatcher	11.7g	2-3 birds	Aerial		
Pachyramphus aglaiae	Cabezón plomizo	Rose Throated Becard		Solitary	Aerial		
Manacus aurantiacus	Saltarín cuellinaranja	Orange Collared Manakin	15.5 g	Solitary	Aerial		
Euphonia luteicapilla	Eufonía coroniamarilla	Yellow Crowned Euphonia	13 g	Solitary	Aerial		

Scientific name	Common name (Spanish)	English Name	Average Weight	Typical Group Size	Travel Preference	Comments	Picture
Syvilagus brasilencis	Muleto	Tapeti	990g	Groups of up to 20	Terrestrial		
Ortalis cinereceps	Paisana	Grey-headed chachalaca	500g	Solitary	Aerial		
Leopotila verreauxi	Paloma Rabiblanca	White-tipped dove	115g	Solitary	Aerial		
Penelope purpurascens	Pava	Crested Guan	1750g	Family groups of 6-12	Aerial		

Scientific name	Common name (Spanish)	English Name	Average Weight	Typical Group Size	Travel Preference	Comments	Picture
Crypturellus soui	Perdiz	Little Tinamou	220g	Solitary	Aerial		
Columba cayennensis	Torcaza	Pale-vented Pigeon	240g	Solitary but may form small groups at drinking areas	Aerial		
Ramphastos sulfuratus	Tucán	Keel-billed Toucan, Rainbow-billed Toucan, Sulphur-breasted Toucan	440g	Flocks of 6-12	Aerial		

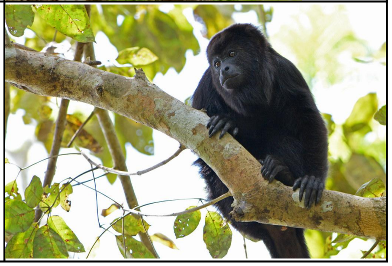
Scientific name	Common name (Spanish)	English Name	Average Weight	Typical Group Size	Travel Preference	Comments	Picture
Amazona autumnalis	Loro moñiroja	Red-lored Amazon	395g	Solitary	Aerial		
Amazona ochrocephala	Loro moñiamarilla	Yellow-crowned Amazon	430g	Solitary unless with mate	Aerial		

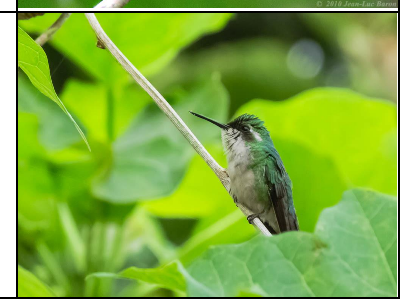
Scientific name	Common name (Spanish)	English Name	Average Weight	Typical Group Size	Travel Preference	Comments	Picture
Brotogeris jugularis	Periquito barbinaranja	Orange-chinned Parakeet	59g	Social with strong pair bond	Aerial		
Crocodylus acutus	Caimán Aguja	American Crocodile	400kg	Solitary	Terrestrial		
Boa constrictor	Boa	Boa constrictor	15kg	Solitary	Terrestrial		

Scientific name	Common name (Spanish)	English Name	Average Weight	Typical Group Size	Travel Preference	Comments	Picture
Trachemys scripta	Gocotea	Pond slider	240g	Groups	Terrestrial		
Iguana iguana	Iguana Verde	Green Iguana	9.1kg	Solitary or in small groups up to 5	Semi-Arboreal		
Ctenosaura similis	Iguana Negra	Black Iguana	5kg	Large groups, but little interaction between iguanas	Semi-Arboreal		
Caluromys derbianus	Zarigüeya de cuatro ojos	Derby's woolly opossum	300g	Solitary	Arboreal		

Scientific name	Common name (Spanish)	English Name	Average Weight	Typical Group Size	Travel Preference	Comments	Picture
Choloepus hoffmanni	Perezoso de dos garras	Hoffmann's Two-toed Sloth	5kg	Solitary	Semi-arboreal		
Cebus capucinus	Mono capuchino	White-headed Capuchin	3.9kg	Groups of 16	Arboreal		
Procyon cancrivorus	Mapache	Crab-eating raccoon	6kg	Solitary	Terrestrial, semi-arboreal		

Scientific name	Common name (Spanish)	English Name	Average Weight	Typical Group Size	Travel Preference	Comments	Picture
Potos flavus	Cusimbi	Kinkajou, honey bear	3kg	Solitary or family groups	Arboreal		
Sciurus variegatoides /Sciurus richmondi	Ardilla	Variegated Squirrel /Richmond's Squirrel	500g	Groups of up to 3	Arboreal		

Scientific name	Common name (Spanish)	English Name	Average Weight	Typical Group Size	Travel Preference	Comments	Picture
Crocodylus moreletii	Cocodrilo de pantano	Belize Crocodile, Morelet's Crocodile, Central American Crocodile	48kg	Solitary			
Canis latrans	Coyote	Coyote	11.5kg	Packs up to 20	Terrestrial		
Alouatta palliata	Mono aullador	Mantled Howler	9.8kg	Groups of up to 40	Arboreal		
Alouatta pigra	Saraguato negro	Guatemalan black howler	7kg	Packs up to 20	Arboreal	Very abunant in panama	

Scientific name	Common name (Spanish)	English Name	Average Weight	Typical Group Size	Travel Preference	Comments	Picture
Pionopsitta pyrilia	Loro cabeza amarilla	Saffron-headed parrot	190-300 g	Solitary unless with mate	Aerial		
Carpodectes antoniae	Cotinga piquiamarillo	Yellow Billed Cotinga	98g	Groups of 2	Aerial		
Thamnophilus bridgesi	Batara negruzco	Black Hooded Antshrike	27g	Solitary	Aerial		
Chlorostilbon assimilis	Esmeralda jardinera	Garden Emer	3.1g	Solitary	Aerial		

Scientific name	Common name (Spanish)	English Name	Average Weight	Typical Group Size	Travel Preference	Comments	Picture
Pteroglossus frantzii	Tucancillo piquiamarillo	Fiery-billed Aracari	250g	Small flocks of up to 10 birds	Arboreal		

Catalog of Batipa's Flora

Scientific Name	Common Name (Spanish)	English Name	Type of Vegetation	Size (Root/Height)	Comments	Picture
Serjania mexicana		Sopaberry	Climbing woody plant	Grow up to 4m in height		
Epidendrum sp.	Orquídea	Orchid	Large neotropical genus of the orchid family			
Anthurium sp.	Calas	Tailflower, Flamingo Flower, Laceleaf, Anthurium	Includes about 1000 species of flowering plants		They thrive in moist soils with high organic matter	
Philodendron sp.	Filodendro		Large genus of flowering plants in the family Araceae	Have both aerial and subterranean roots		

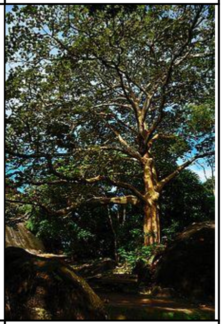
Scientific Name	Common Name (Spanish)	English Name	Type of Vegetation	Size (Root/Height)	Comments	Picture
Syngonium sp.	Singonio		Genus of flowering plants in the family Araceae	Woody vine 10-20m in height	As a creeper, it needs support. It can also be grown as a groundcover plant; Needs systematically watered humus soil	
Tillandsia sp.	Tillandsia / Clavel del aire	Airplants	Genus of around 650 species of evergreen, perennial flowering plants in the family Bromeliaceae	Minimal root system and grown of shifting desert soil	Capable of rapidly absorbing water that gathers on them; also commonly known as "airplants" because of their propensity to cling wherever conditions permit: telephone wires, tree branches, bark, bare rocks, etc.	
Virola sp.	Miguelario		Genus of medium-sized trees such as nutmeg		Glossy, dark green leaves and clusters of tiny yellow flowers; Emit a pungent odor	

Scientific Name	Common Name (Spanish)	English Name	Type of Vegetation	Size (Root/Height)	Comments	Picture
Inga sp.	Guaba	Ice-Cream-Bean	Genus of small tropical, tough-leaved, nitrogen-fixing trees and shrubs; Subfamily Mimosoideae			
Sloanea sp.	Terciopelo		Genus of flowering plants in the family Elaeocarpaceae; Comprising of about 150 species			
Casearia sp.	Espino Blanco		In the family Salicaceae; a flowering plant.			
Aphelandra sp.	Afelandra / Planta cebra		Evergreen shrub	Grow 1-2m tall	The flowers are produced in dense spikes, with brightly coloured bracts	
Calliandra sp.	Calliandra	Powder-puff	Flowering plants in the pea family	Can grow to 6m tall	Flower all year round	

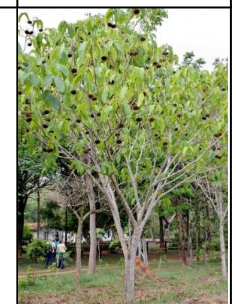
Scientific Name	Common Name (Spanish)	English Name	Type of Vegetation	Size (Root/Height)	Comments	Picture
Cyclopeltis semicordata			Fern	Grow 1-2m tall	Prefers shaded positions, avoid exposure to direct sunlight	
Lygodium venustum	Culebrina / Hierba de la víbora		Climbing fern	Segments up to 12cm long	It is found in humid forests, pine forests , dry forests, and grasslands	
Piper reticulatum	Gusanillo		Tree or shrub			
Trigonidium agertonianum	Orquídea	Orchid	Flower			
Acacia collinsii	Cachito / Cuernito		Flowering plant			

Scientific Name	Common Name (Spanish)	English Name	Type of Vegetation	Size (Root/Height)	Comments	Picture
Barleria micans			Grass			
Gouania lupuloides	Bejuco leñatero	Chewstick	Neotripocal plant, woody vine		Whitens teeth	
Momordica charantia	Melón amargo	Bitter Melon	Woody vine			
Mimosa pudica	Mimosa sensitiva	Sensitive plant	Creeping annual flowering plant	Less than 1m	Flourishes in nutrient deprived soil	
Heliconia latispatha	Heliconia	Expanded lobsterclaw	Flower	Up to 4m		

Scientific Name	Common Name (Spanish)	English Name	Type of Vegetation	Size (Root/Height)	Comments	Picture
Faramea occidentales	Garrotillo / Benjamín		Evergreen shrub or tree	5m tall	Harvested locally for wood	
Urera baccifera	Ortiga	Scratchbush	Shrub or small tree	2-4m tall shrub or up to 7m tall tree	Because of its stinging prickles, the plant is widely grown as an impenetrable hedge, and is also used as a source of fiber	
Plumeria acutifolia	Caracucha	Nosegay	Spreading shrub or small tree	2-8m tall		
Passiflora vitifolia	Granadilla de monte	Grape-Leaved Passion Fruit	Perennial Climber		The edible fruit is sometimes gathered from the wild and consumed locally, though it is not widely used	
[redacted]						
Cordia alliodora	Laurel	Spanish Elm	Tree	Up to 35m tall		

Scientific Name	Common Name (Spanish)	English Name	Type of Vegetation	Size (Root/Height)	Comments	Picture
Sterculia apetala	Panamá	Panama Tree	Perennial and deciduous tree with large root base	Up to 40m tall		
Guazuma ulmifolia	Guácimo	Bay cedar	Tree	Grows up to 20m tall		
Quararibea asterolepis	Guayabillo		Evergreen Tree	25-35 m tall	Projecting outward from the base are exceptionally thin, flat, and straight buttresses that meld with the trunk at a height of about 1.5m	
Swietenia macrophylla	Caoba	Mahogany	Perennial tree	Up to 35m tall		

Scientific Name	Common Name (Spanish)	English Name	Type of Vegetation	Size (Root/Height)	Comments	Picture
Chysophyllum cainito	Caimito	Cainito			Grows 10-25m tall. Perennial and grows rapidly	
Calophyllum longifolium	Santa María		Evergreen tree	25-35m tall		
Anacardium excelsum	Espavé		Tree	Perennial grows up to 45m tall		
Pseudobombax septenatum	Barrigón	Wild cashew	Tree	Evergreen tree grows to be 48m tall		
Tabebuia rosea	Roble	Pink poui	Flowering tree	40m tall	Germination of seeds is almost 100%	

Scientific Name	Common Name (Spanish)	English Name	Type of Vegetation	Size (Root/Height)	Comments	Picture
Bursera simaruba	Cholo pelado	Gumbo-limbo	"Tourist tree" tree with red peeling bark like the skin of a sunburnt tourist	Up to 30m tall		
Zuelania guidonia	Cagajón/ Árbol Caspa	Zuelania	Deciduous tree with a high, thin, pyramidal crown	10-25m tall		
Apeiba tibourbou	Peine de mono		Evergreen Tree with a flat, spreading crown	Up to 15m tall	Alternative fiber crop to make paper	
Albizia guachapele	Iguá/ Tabaca	Silk tree	Tree	15m		
Enterolobium cyclocarpum	Corotú	Devil's Ear	Deciduous Tree	25m tall	Older trees develop small buttresses and produce large roots that run along the surface of the ground for 2-3m	

Scientific Name	Common Name (Spanish)	English Name	Type of Vegetation	Size (Root/Height)	Comments	Picture
Hura crepitans	Tronador	Sandbox tree	Semi-deciduous tree	Typically 12-20m tall but can grow up to 50m tall	The tree is harvested from the wild for local use as a medicine and source of materials. The wood is sometimes traded. The tree is grown to provide shade in plantations	
Cedrela odorata	Cedro	Spanish cedar	Tree of the New World Tropics	10-30m tall	Appears in moist and seasonally dry subtropical or tripical life zones and on well-drained soils	
Pochota quinata	Cedro espino	Hawthorn Cedar	Tree			
Castilla elastica	Caucho	Panama Rubber Tree	Deciduous to Evergreen tree	10-30m tall but exceptionally to 60 m	Local source of latex	

Scientific Name	Common Name (Spanish)	English Name	Type of Vegetation	Size (Root/Height)	Comments	Picture
Luehea semannii	Guácimo colorado		Evergreen tree	10-40m tall	Often strongly buttressed with buttresses up to 2m high	
Astrocaryum standleyanum	Palma negra / Chunga	Chumba wumba, Black palm	Species of palm	6-15m tall		
Guarea grandifolia	Chuchupate		Evergreen Tree	Up to 50m tall	Buttresses up to 4 m high	
Annona purpurea	Toreta	Soncoya	Deciduous Tree	6-10m tall		

After compiling lists of both fauna and flora, the information was used for various design aspects of the crossing. A key consideration for determining the vegetation used to populate the crossing was the amount of soil backfill to be used. In order to ensure that the crossing was not overloaded with soil, but could still accommodate deep roots, it was determined that the soil backfill height from the crown of the arch should be 2.44 meters (8 feet). This soil depth ruled out the use of most large tree species that could pose threats to the sustainability of the bridge, especially if one were to fall into the highway. With this established soil depth of 2.44 meters (8 feet), vegetation on the crossing was limited to a maximum height of 3 meters (9.84 feet) and an average root depth of 1.52 meters (5 feet). The taller trees from the catalogue would not be included on the crossing, but rather be placed along the highway near the entrance to the crossing to more seamlessly blend the surroundings with the crossing.

After gaining an understanding of the stakeholders' needs and concerns, the official design process could begin. The first step to doing this was measuring the area of focus in order to create a correctly scaled design. The highway measurements were determined using a combination of the Google Earth measuring tool and in-person confirmation. Through Google Earth, it was determined that the total width of Highway 1 in the area of focus is approximately 30.48 meters (100 feet) (Figure 24).

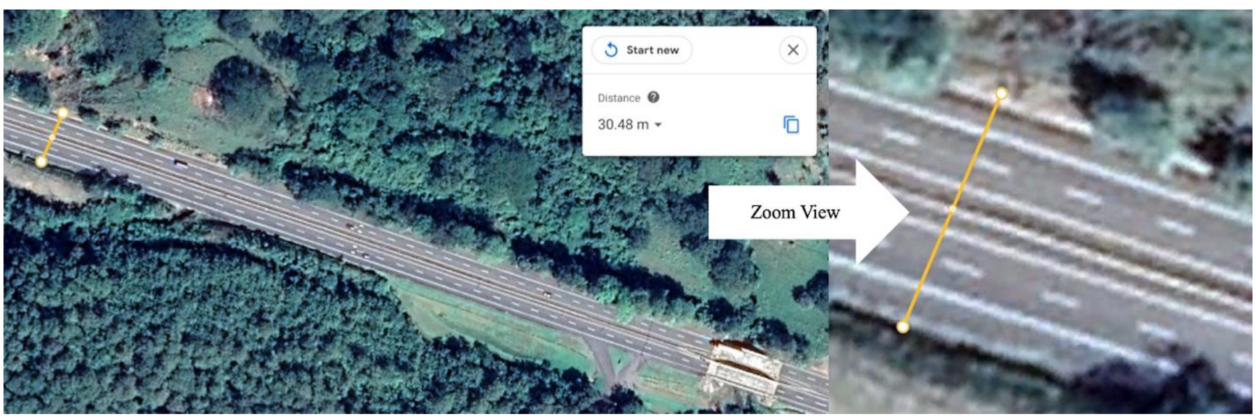


Figure 24: Google Earth Measurement Process.

After determining the width of the highway, the interval measurements necessary for designing the crossing were found. By utilizing standard jersey barrier dimensions, the distance from each edge to the center barrier, width of lanes, and width of highway shoulders were determined (Figure 25). The full list of dimensions is represented in Table 9.

Table 9: Critical Highway Measurements.

Parameter	Measured Value
Width of Highway 1 (ft)	100
Width of Travel Lane (ft)	15
Width of Travel Lane Buffer to Edge of Pavement (ft)	8
Width of Dirt Buffer (ft)	4
Width to Jersey Barrier (ft)	2

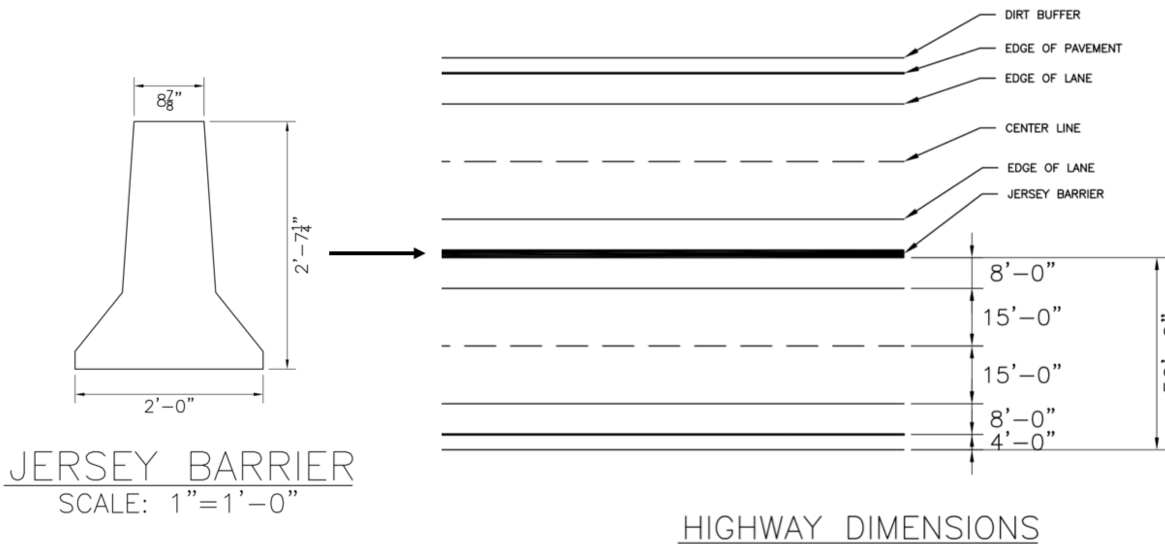


Figure 25: AutoCAD Representation of Highway Dimensions Utilizing Standard Jersey Barrier.

In addition to creating a scalable design, knowing the measurements helped to determine which material could be used for construction that would be able to span the length and width needed; and with stakeholder input, a definitive material was selected to be used for the structure. Concrete was decided on as the main material to be used for the overpass because it is familiar to and commonly used on Panamanian construction sites. In addition, it is sustainable, cost-effective, and easily accessible.

Once the area was surveyed and the necessary measurements were taken, designing the crossing itself could finally begin. Designing the crossing was a process with a number of steps including a preliminary visual design and refinement based on structural calculations. In AutoCAD two potential crossing profiles were created and presented to stakeholders with proposed location, aesthetic design, and size (Figure 26).

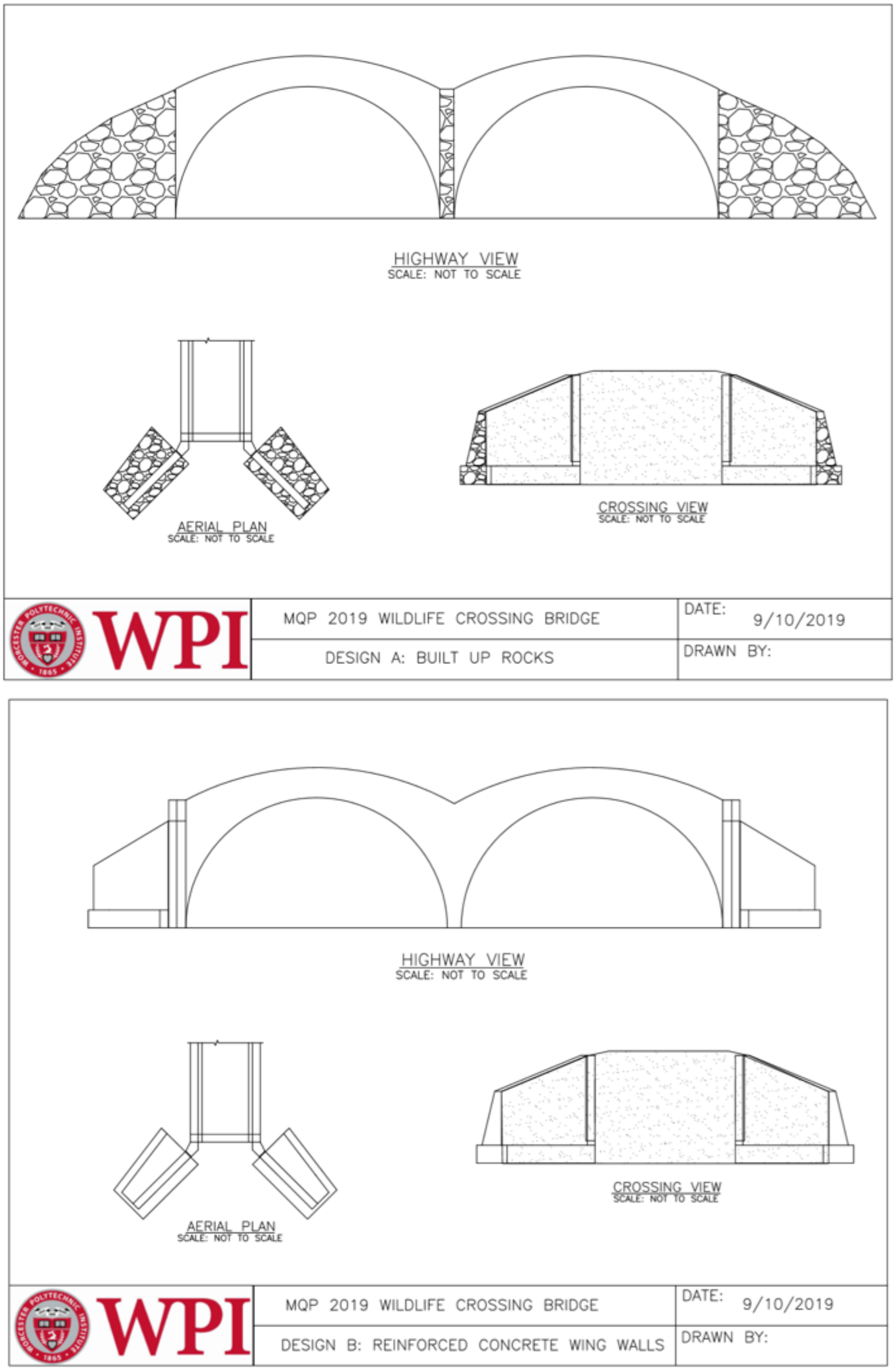


Figure 26: Initial Crossing Design Drawings in AutoCAD.

The two initial designs both functioned the same, but varied in visual appearance. Design A was a concrete structure with stones placed around the base for a more visually appealing and natural look. This was based off of Banff's national park overpass discussed previously within the case studies section. Design B was a more traditional concrete structure with no additional rocks on the outside. After discussing the two designs, the sponsor preferred Design B without the rock detailing. The chosen design was developed further for structural soundness, and in order to create the same visual effect as Design B without the added cost of the rocks, the design was altered to have a cement block design on the front face of the bridge for visual appeal.

The man-made fencing for the overpass was designed as a 16-foot wall extending up from the arch of each tunnel. Once constructed, these cement walls would be filled with soil backfill, which would fill 50% of this height (about eight feet). The remaining eight feet would extend above the soil and act as a barrier for animals that will be using the crossing. In addition to the concrete wall lining the crossing, it is designed with a dense barrier of shrubs and bushes to act as a sound and light barrier for the animals. The two most prevalent plants to be included in this barrier include vetiver to combat erosion and calamondin shrubs, which can grow up to three meters tall and are perfect for helping as a sound and light barrier from the highway. A large variety of other plants native to the area will be included in the barrier and across the overpass in order to create continuity with the surrounding environment. These plants were chosen based on the catalog of flora that was developed.

Based on the measured dimensions of the highway and the requirements of the bridge for stakeholders and end users, the following dimensions of the bridge were initially designed:

Table 10: Key Dimensions of Crossing Design.

Crossing Dimensions	
Number of Tunnels	2
Width of Tunnel opening (ft)	65.6
Length of Tunnel (ft)	250
Height of Tunnel opening (ft)	29.5
Arch Slab Thickness (ft)	1.31
Arch Slab Width (ft)	3.28
Arch Slab Length (ft)	48.96
Volume of Concrete per Slab (ft^3)	210.37
Number of Arch Slabs per Tunnel	152.44
Number of Reinforcing Steel Bars per Arch Slab	6
Reinforced Steel Bar Size	#5

To evaluate the loading conditions and combinations, the limit states were defined using criteria from the AASHTO LRFD Bridge Design Specifications (Table 11). The fatigue limit state was not defined because it is determined based on the truck traffic. Since the crossing is not to be used by anything but animals, this design parameter was not considered.

Table 11: Limit States of Crossing Design Based on AASHTO Bridge Design Specifications.

Limit States	
Service	I
Strength	V
Fatigue	N/A
Extreme Event	I
Risk Category	II
Exposure Category	B

Using the limit states and specific conditions to the crossing location, the loads were calculated:

Table 12: Elements Contributing to Total Dead Load Calculation.

Dead Loads (DL)	
Governing Equation	$DL = V \times \lambda$
Vegetative Unit Weight, λ (kcf)	Negligible
Soil Type	Stiff glacial clay
Soil Unit Weight, λ (kcf)	0.13
Soil Backfill Volume, V (ft^3)	455,317.5
Soil DL (kips)	58,735.96
Reinforced Concrete Unit Weight, λ (kcf)	0.15
Volume of Reinforced Concrete, V (ft^3)	64,137.6
Structure Self Weight DL (kips)	9,620.64
Total DL (kips)	**68,356.6**

Table 13: Elements Contributing to Total Wind Load Calculation.

Wind Load (W)	
Governing Equations	$q=0.00256(K_z)(K_{zt})(K_d)(V^2)$ $WS = (\frac{q \times A}{1000})$
Risk Category	II
Exposure Category	B
Exposure Velocity Pressure Coefficient, K_z	0.81
Topographic Factor, K_{zt}	1
Directionality Factor, K_d	0.85
Basic wind speed, V (mph)	80
Effective Velocity Pressure, q (psf)	11.28
Surface Area of Crossing Face, A (ft^2)	2,929.79
Total WS (kips)	**33.05**

Table 14: Elements Contributing to Total Seismic Load Calculation.

Seismic Load (E)	
Governing Equation	$EQ = \frac{(m \times PGA)}{3217.41}$
Peak Ground Acceleration, PGA (ft/s^2)	9.84
Mass of Crossing, m (lbm)	929,995.20
Inertial Force due to Earthquake (lbf)	2,844.99
Total E (kips)	**2.845**

Table 15: Elements Contributing to Total Live Load Calculation.

Live Loads (LL)	
Governing Equation	$LL = \frac{(SA \times P)}{1000}$
Pressure Exerted by Animals, P (psf)	0.9
Crossing Structure Surface Area, SA (ft^2)	32,800
Total LL (kips)	**29.52**

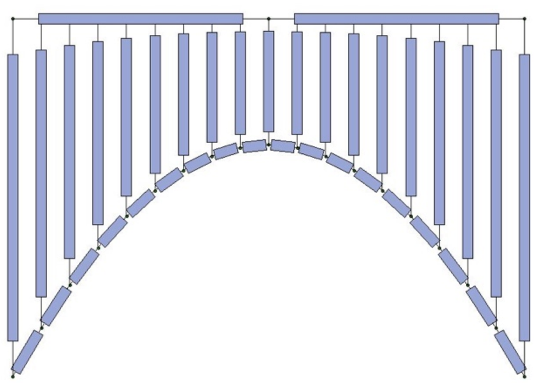
The live load was negligible from the load calculations because it was insignificant in comparison to the dead load exerted on the crossing by the soil and structure weight itself. Using the calculated loads and the determined limit states, the potential load combinations from Table 16 were calculated.

Table 16: Load Combination Equations Based on State Limits.

Load Combination	Load Multipliers	Total Loading (kips)
Service 1	1.00 DL + 1.00 LL + 1.00 WS	63,389.65
Strength V	1.25 DL + 1.35 LL + 1.00 WS	85, 478.80
Extreme Event 1	1.25 DL + 0.50 LL + 1.00 EQ	85, 448.59

The Strength V load combination resulted in the largest loading, and therefore was the governing equation for analysis. The loads calculated in Table 12, Table 13, Table 14, and Table 15 were multiplied by their respective load multipliers and input in RISA 3D for evaluation.

In order to provide an accurate evaluation of the calculations and design, the structure was input into RISA using the ellipse form. The arch was comprised of 18 concrete members with corresponding columns. These columns connected the arch to two horizontal beams 16 feet above the peak of the arch, created to accurately apply the loading to the structure (Figure 27).



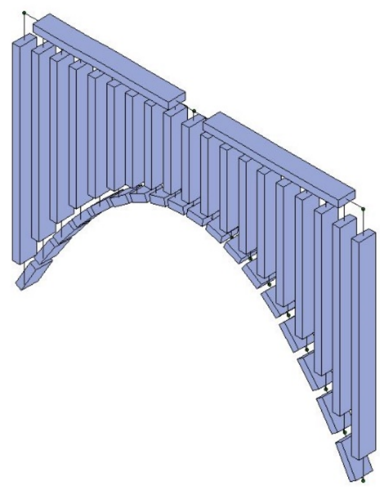
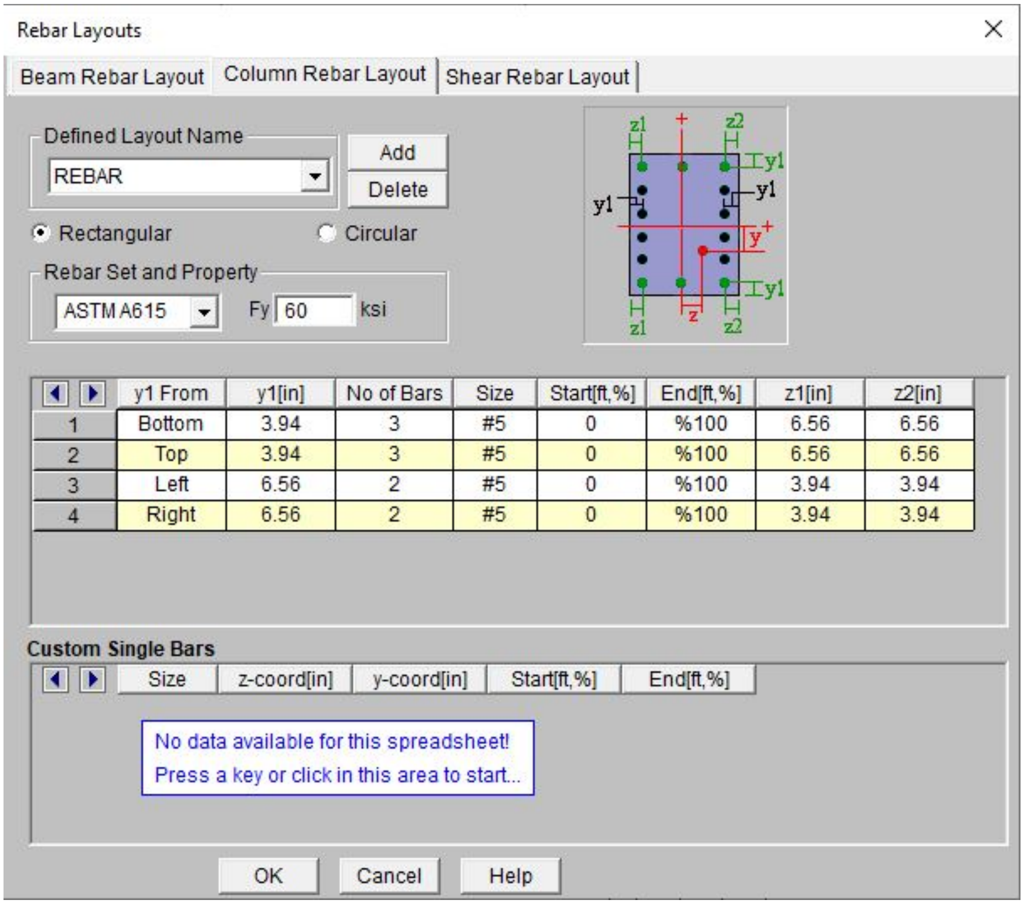


Figure 27: RISA Structural Design Diagrams.

RISA was used to determine the correct number of rebar to be used and which size (Figure 28). The rebar chosen for the slabs was size #5 and was designed to be six rods of rebar running throughout each slab. From left to right, each piece of rebar was spaced 0.16 meters (6.56 inches) from the side of the slab with 0.33 meters (13.12 inches) between each rod of rebar. From top to bottom the rebar was 0.10 meters (3.94 inches) from the top and spaced 0.2 meters (7.88 inches) apart. Based off of the calculations done in RISA this was structurally stable.



	y1 From	y1[in]	No of Bars	Size	Start[ft,%]	End[ft,%]	z1[in]	z2[in]
1	Bottom	3.94	3	#5	0	%100	6.56	6.56
2	Top	3.94	3	#5	0	%100	6.56	6.56
3	Left	6.56	2	#5	0	%100	3.94	3.94
4	Right	6.56	2	#5	0	%100	3.94	3.94

Figure 28: RISA Determination of Rebar Placement and Sizing.

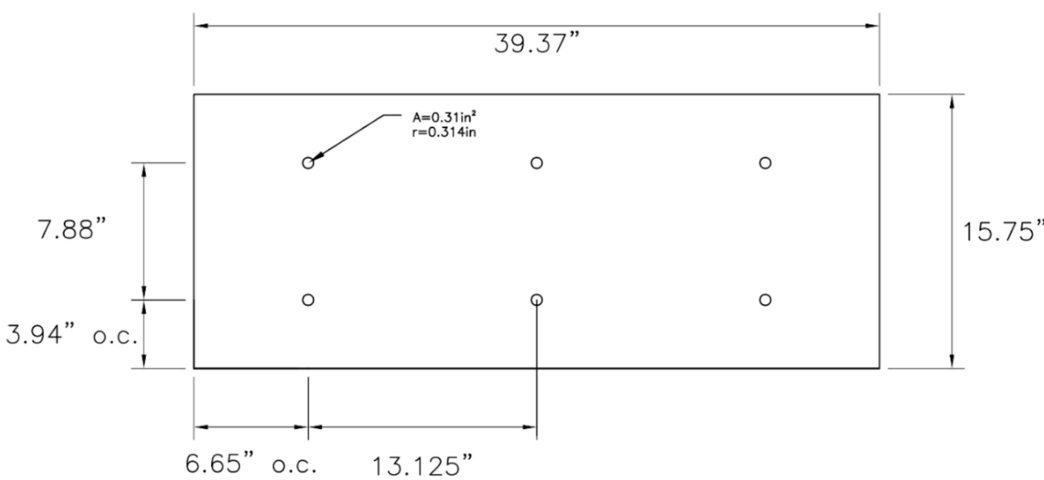


Figure 29: AutoCAD Drawing Representation of Rebar Placement and Sizing in Arch Slab.

Four sets of loading were applied to the structure in RISA: wind load, seismic load, soil weight, and self-weight (Figure 30). The wind load was applied as a distributed load of -11.28 k/ft in the

Z-direction on all members. This acted as base load case (BLC) 1. The seismic load was applied as point loads of 711 k/ft in the X- and Z-directions on the base points of the arch. This acted as BLC 2. The soil weight was applied as a distributed load of -1476 k/ft on the ends of the horizontal beams above the arch in the Y-direction and -951 k/ft in the center of these beams. This acted as BLC 3. The self-weight was applied as a distributed load of -1.07 kips/ft in the Y-direction on each of the 18 arch members. This acted as BLC 4.

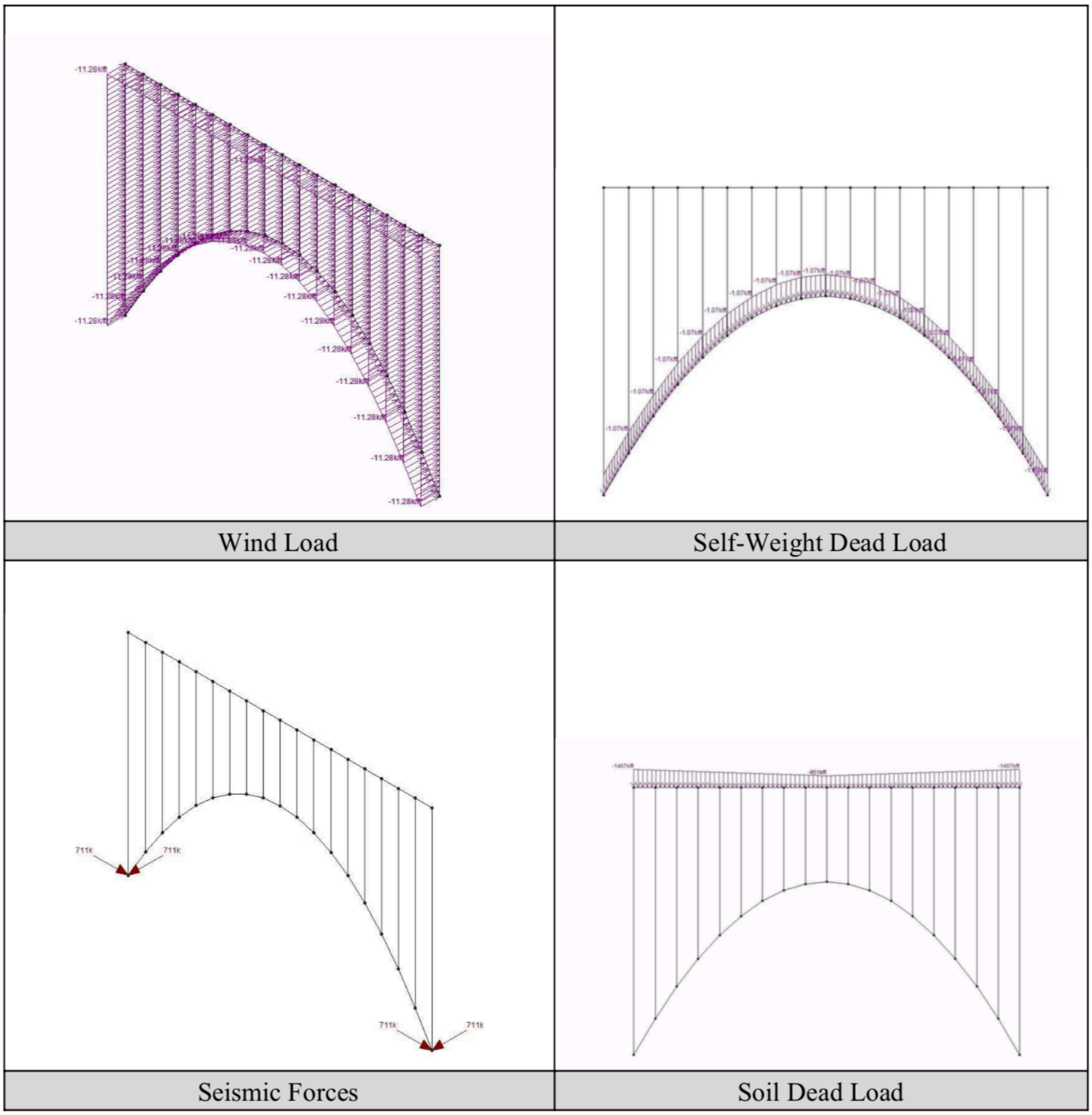


Figure 30: RISA Diagrams of Four Basic Loading Conditions.

The four base load cases were then applied to the structure as a load combination. When solved by RISA the axial, shear, torque, and moment were provided (Figure 31). Each of these diagrams provided a check of stability for the structure by confirming an equilibrium of forces. The load

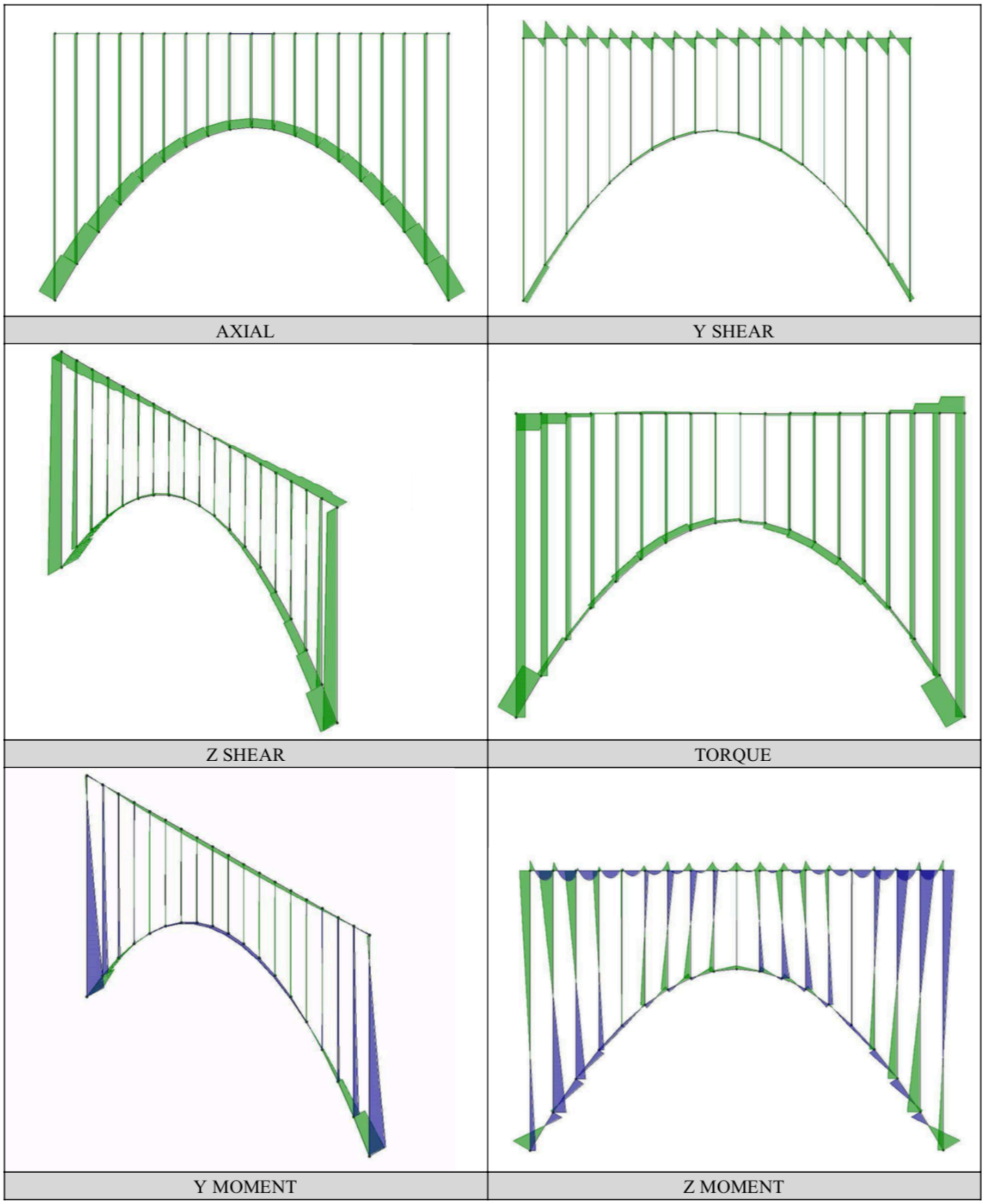


Figure 31: RISA Reaction Diagrams from Loading Combinations.

combination that was determined to produce the maximum impact on the structure is Strength V (Table 16). The diagrams below are accurate of both load combinations evaluated.

When comparing these load combinations, the variance of impact was evident. Load combination Strength V displayed greater maximum axial force, z-shear, and z-moment values. This confirmed the calculations performed regarding potential load combinations and the maximum loading were correct and structurally sound. The loading impact on each member was determined by the software and a diagram of the member placement was provided (Figure 32).

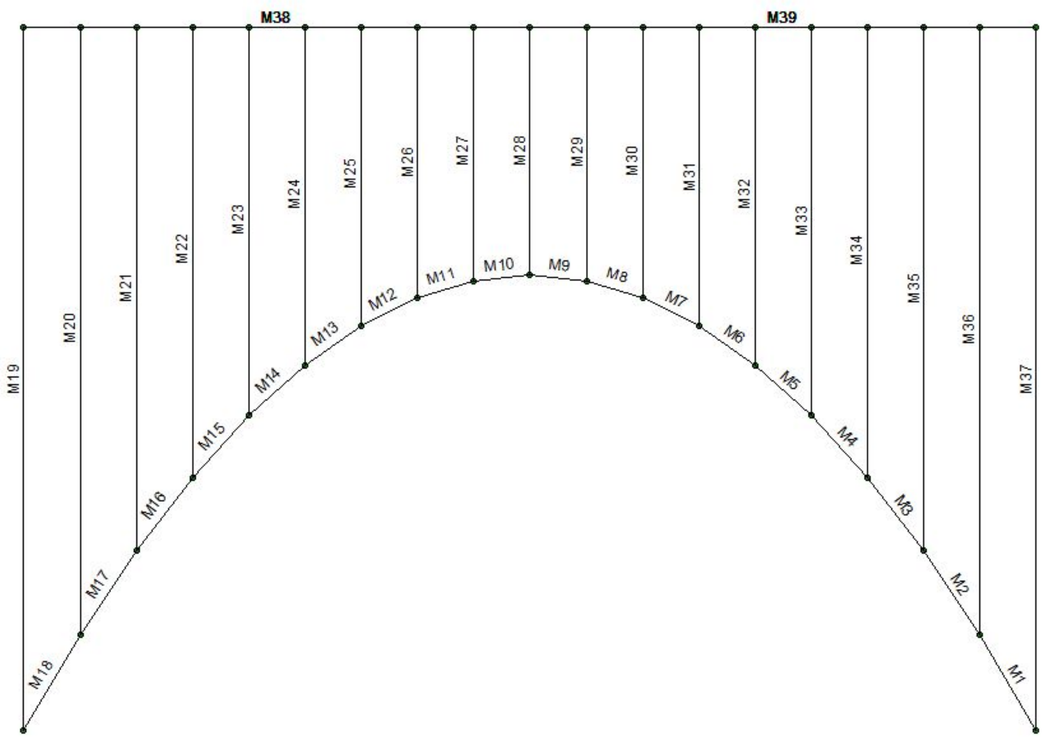


Figure 32: RISA Member Diagram.

The global parameters were proven to be balanced in each respective direction (x-, y-, and z-). Additionally, the maximum and minimum values for each parameter (axial, shear, torque, etc.) were identified and gathered for a more in-depth analysis in each load combination (Table 17 and Table 18). The axial forces applied to the structure showed a maximum value at the edges of the arch with a minimum value at the center of the horizontal beam, closest to the peak of the arch. This is a result of the maximum soil backfill being applied to edges of the arch and the seismic loads being focused in these areas. Similar observations were made for each of the shear, torque, and moment results. Each of these parameters reflected the magnitude and location of the base load cases applied.

Table 17: Maximum and Minimum Loading of All BLC's With a Single Factor.

All Loads	Axial		Y Shear		Z Shear		Torque		Y Moment		Z Moment	
	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN
Member	1 & 18	38 & 39	38	39	18	1	18	1	1 & 18	19 & 37	1 & 18	36
Load (kips)	41,674	-47	3,380	-3,380	2,039	-2,039	7,960	-7,960	56,111	-60,940	3,817	-2,710

Table 18: Maximum and Minimum Loading of Strength V Load Combination.

Strength Y	Axial		Y Shear		Z Shear		Torque		Y Moment		Z Moment	
	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN
Member	1 & 18	38 & 39	38	39	18	1	18	1	1 & 18	19 & 37	1 & 18	36
Load (kips)	52,092	-58.7	4,225	-4,225	2,039	-2,039	7,960	-7,960	56,111	-60,940	4,771	-3,388

The y-shear results showed the equilibrium spread throughout the structure. The local minimum and maximum located on the upper horizontal beams in comparison to those of the lower arch were reversed. The local minimum of the upper beam was at the far right while the local minimum of the lower arch was at the far left. Similarly, the local maximum of the upper beam was at the far left while the local maximum of the lower arch was at the far right. Although this is not reflected in the table above as the global minimum and maximum both reside on the upper horizontal beam, it strengthens the validity of the design.

After completing the crossing design both aesthetically and structurally, it was necessary to represent the proposal in a number of ways that would make it clear to stakeholders. Three platforms were used in order to give a visual of proposed location, structural makeup, and functionality. The first deliverable was an image of the proposed crossing location (Figure 33). This was created using photoshop to superimpose an aerial view of the crossing over Google Earth where it would be placed. This location was chosen due to its connectivity potential and location relative to Batipa. This proposed location connects the mountains of Gualaca Corridor and the mangroves of Chiriqui Gulf, two habitats previously sliced by Highway 1. Because the crossing would be near to a canopy crossing and ecoduct, it would be part of a larger effort for animals ability to bypass the highway, and this complete connectivity is key to ensuring that species have the ability to migrate and breed across populations. The location is also on the same strip of highway as the entrance to Batipa, which would give attention to the organization's mission of protecting biodiversity.

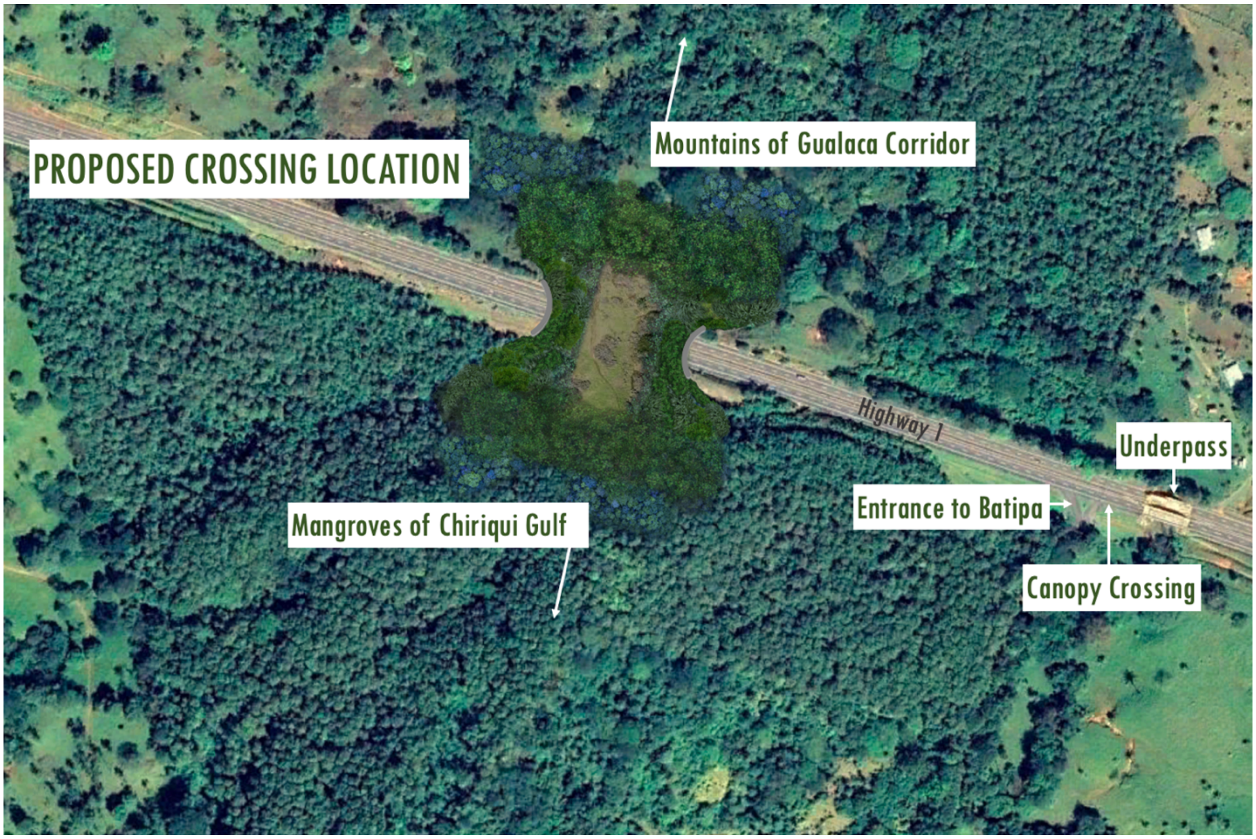


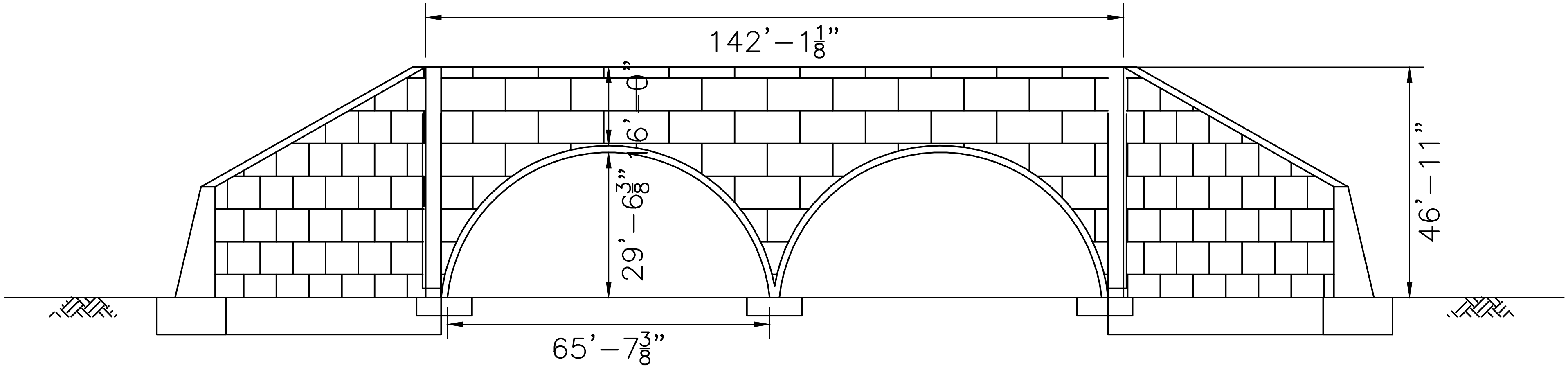
Figure 33: Connectivity Potential Aerial View with Proposed Greenery.

In order to provide a technical representation of the crossing, AutoCAD drawings were created. The first drawing was a simple diagram showing the placement of the bridge across Highway 1 demonstrating the length and the width of the overpass. This was used to ensure that the stakeholders understood the location and placement of the overpass relative to the area. The second drawing (Page 2) shows the plan for how the overpass will look when constructed. The highway view is drawn to scale with a height of 14.3 meters (46 feet 11 inches) and a width of 43.3 meters (142 feet 1⅛ inches), not including the length of the wingwalls. The dimensions of the tunnels are also shown with widths of 20 meters (65.6 feet) and heights of 9 meters (29.5 feet). The height of the wall above the tunnel is 4.9 meters (16 feet). The crossing view (not to scale) represents how the landscaping should look when completed with the tall bushes and shrubs on the edges of the crossing and the smaller plants and grasses in the middle. The third page is the drawings of a wing wall and a slab, that is used to construct the arch way of the tunnels. These are important to know the exact dimensions because they are crucial for the construction of the overpass. The wing wall is demonstrated with all of its dimensions, including the height of 16.6 meters (54.5 feet) and a length of around 20.7 meters (68 feet) and the rebar that should be used to reinforce it. The slab is shown with its standard dimensions: width of 10 meters (34 feet 1½ inches) and height of 9 meters (29.5 feet).

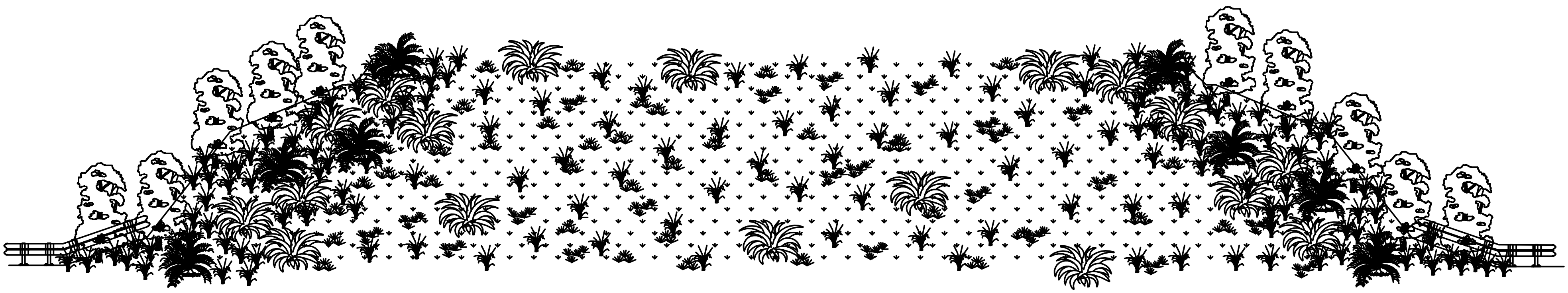
AutoCAD Drawings

WPI	MQP 2019 WILDLIFE CROSSING BRIDGE	DATE: 9/24/2019
	MAP OF PLACEMENT ON HIGHWAY	DRAWN BY: HG, MO, SL, LB

AutoCAD Page 2



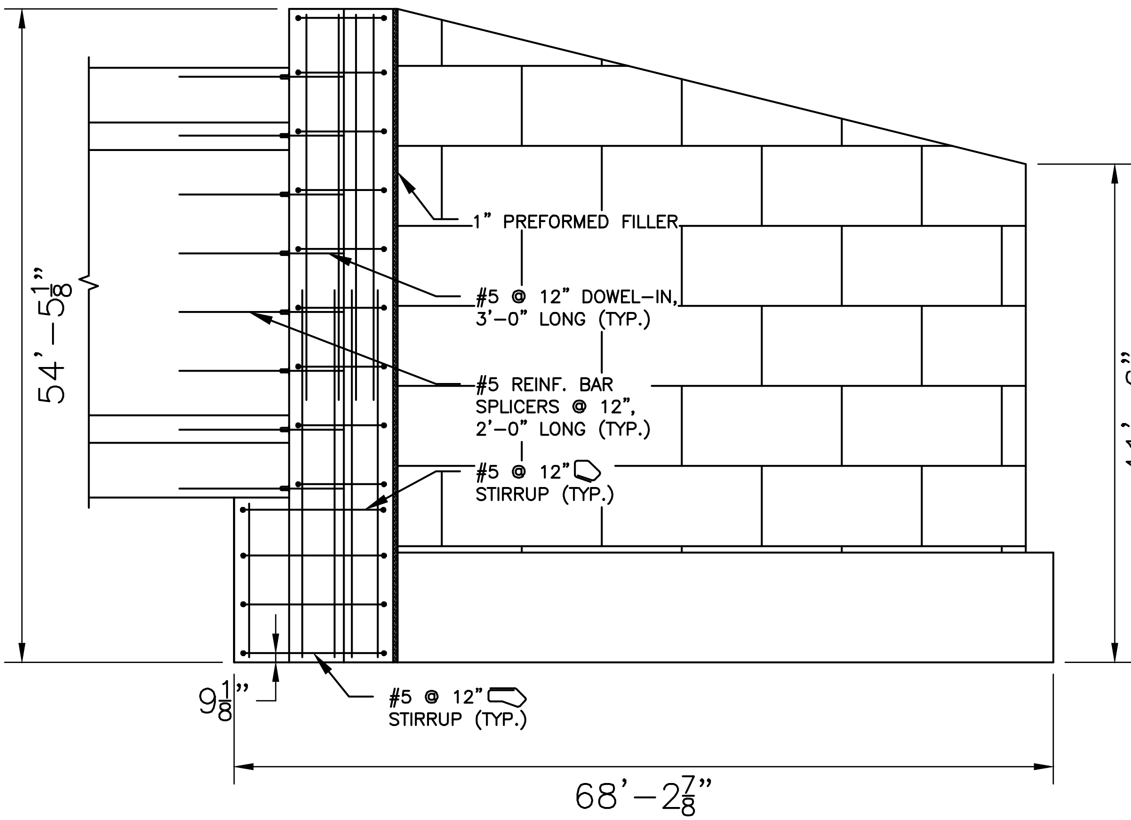
HIGHWAY VIEW
SCALE: 1/32"=1'–0"



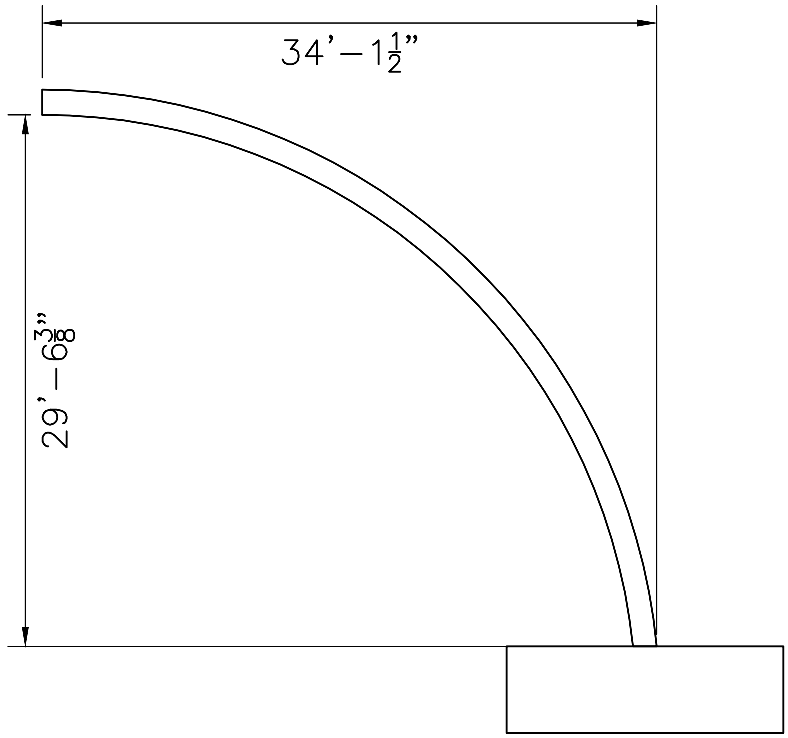
CROSSING VIEW
SCALE: NOT TO SCALE

MQP 2019 WILDLIFE CROSSING BRIDGE	DATE: 9/24/2019
DESIGN A: REINFORCED CONCRETE ARCHES	DRAWN BY: HG, MO, SL, LB

AutoCAD Page 3



WINGWALL
SCALE: 1/16" = 1'-0"



SLAB
SCALE: 1/16"=1'-0"

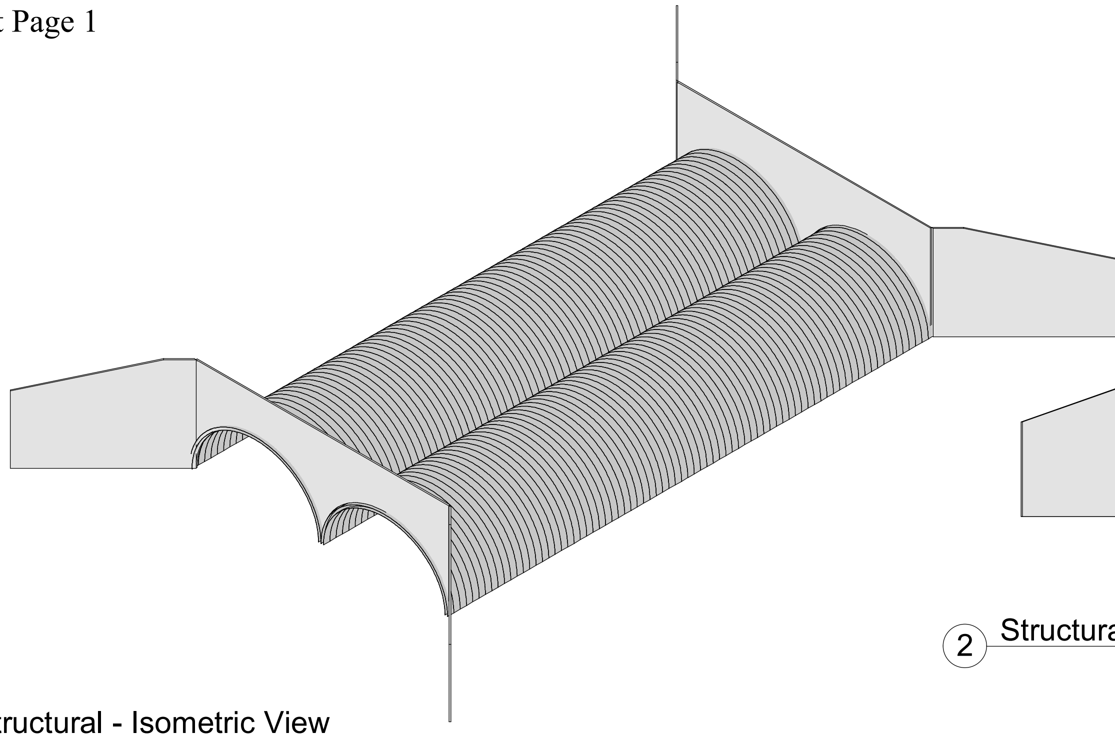
WPI	MQP 2019 WILDLIFE CROSSING BRIDGE	DATE: 9/24/2019
	DESIGN A: REINFORCED CONCRETE ARCHES	DRAWN BY: HG, MO, SL, LB

To provide a visual representation of the overpass, a drawing in Revit was created. This drawing shows the placement on the highway that the overpass will be located and is drawn to scale to show the accurate size of the overpass. The exterior has a concrete finish to represent that concrete will be used in the construction of the overpass. The overpass was created using concrete beams, wingwalls, and boundary walls based on the calculations and AutoCAD drawings. The combination of these elements can be isolated for a visual representation of the structural elements (Page 1).

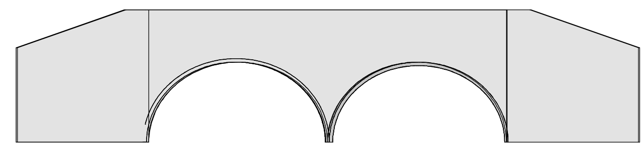
The topography of the land was created to provide a visual of the highway's interaction with the elevation of the overpass. The site views represent this topography with the slope of the crossing at a 5% decrease (Page 2 and Page 3). Along the overpass there are plants shown to represent how they should be placed along the crossing; the taller trees and shrubs will be placed along the edges and smaller bushes and grasses will be placed scattered throughout. There will also be a fencing along the bottom of the overpass closer to the road to help prevent casualties. Several renderings were provided to show a basic concept of the vegetation (Page 4 and Page 5).

AutoDESK Revit Sheets

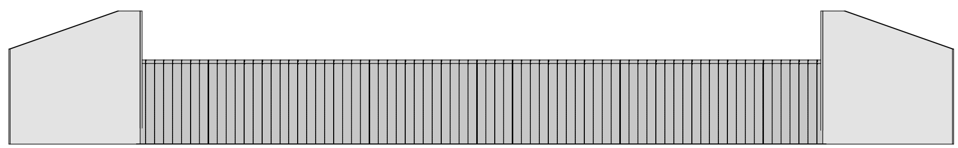
Revit Page 1



1 Structural - Isometric View



2 Structural - Arches View



3 Structural - Side View

WPI

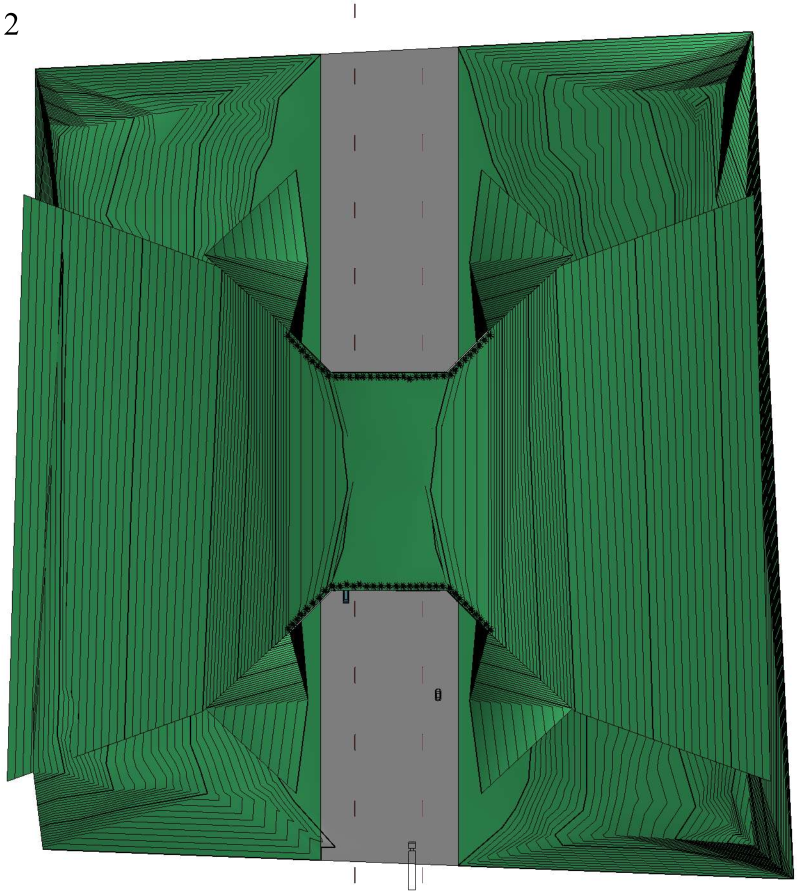
MQP 2019 WILDLIFE CROSSING BRIDGE

STRUCTURAL DRAWINGS

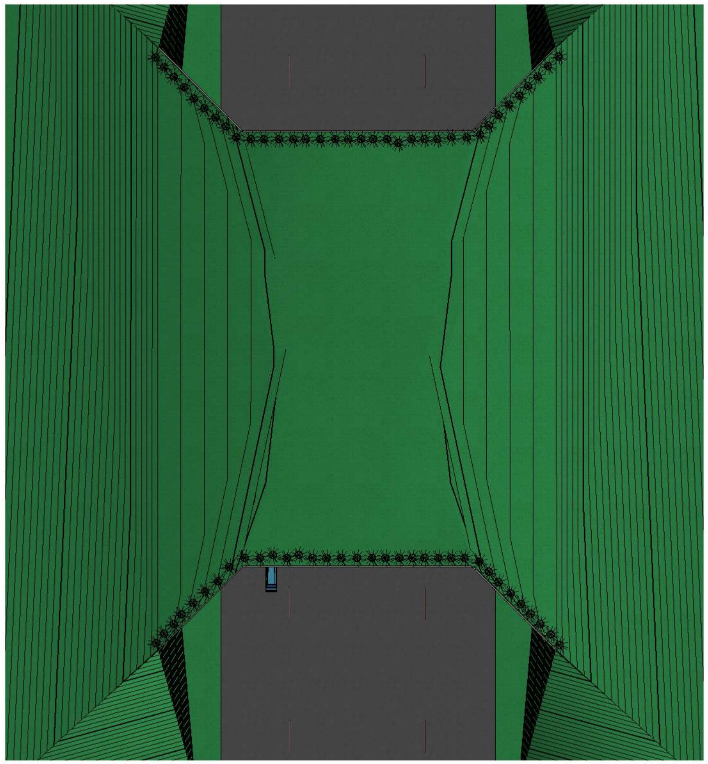
DATE: 9/30/2019

DRAWN BY: LB, HG, SL, MO

Revit Page 2



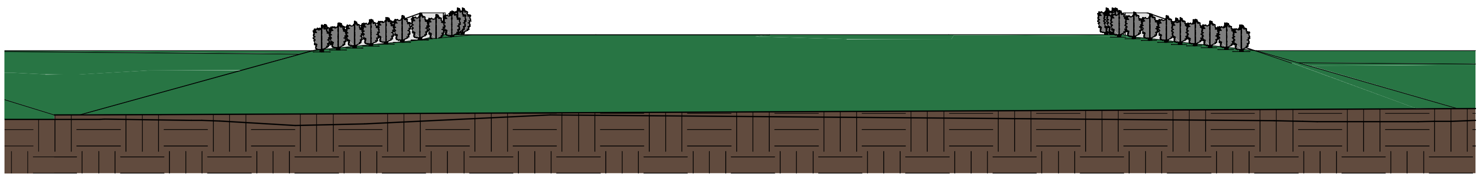
1 Full Site View
1" = 200'-0"



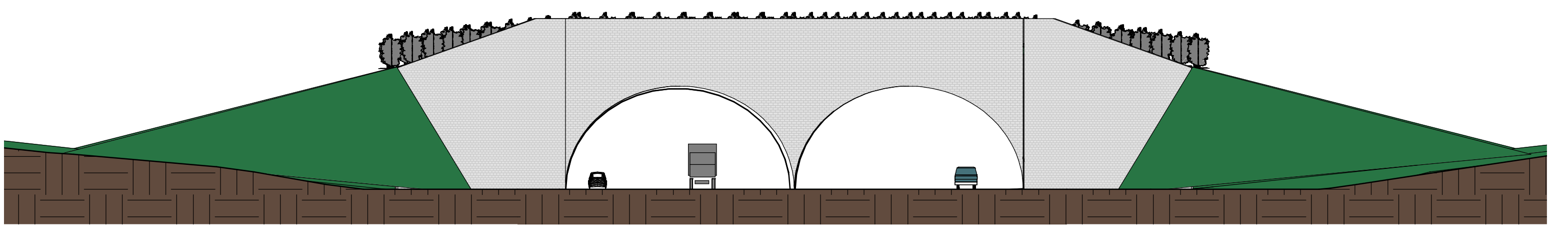
2 Wildlife Crossing Site View
1" = 100'-0"

WPI	MQP 2019 WILDLIFE CROSSING BRIDGE	DATE: 9/30/2019
	SITE VIEW	DRAWN BY: LB, HG, SL, MO

Revit Page 3



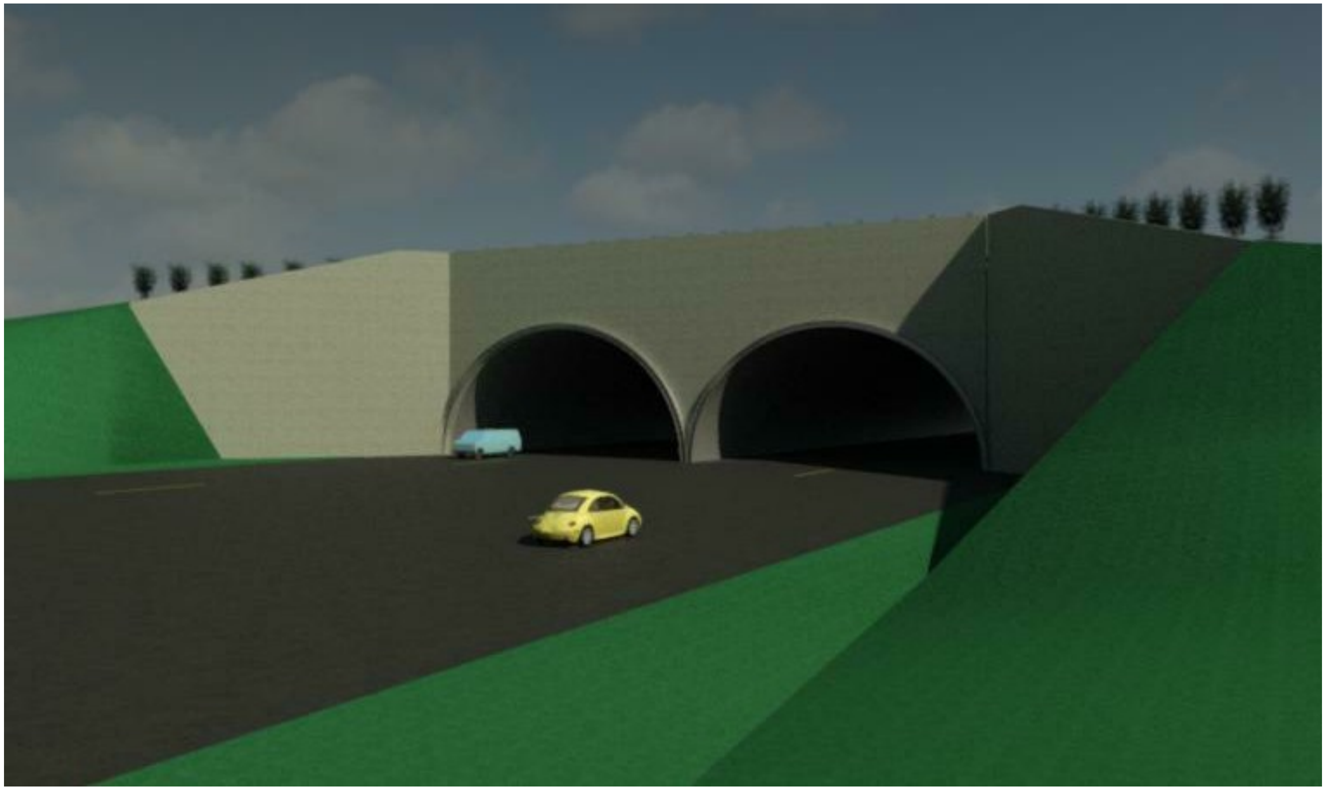
1 East
1/64" = 1'-0"



2 North
1" = 50'-0"

WPI	MQP 2019 WILDLIFE CROSSING BRIDGE	DATE: 9/30/2019
	ELEVATIONS	DRAWN BY: LB, HG, SL, MO

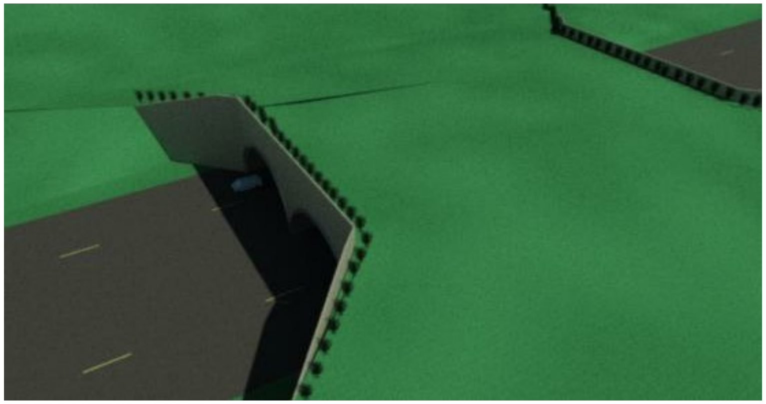
Revit Page 4



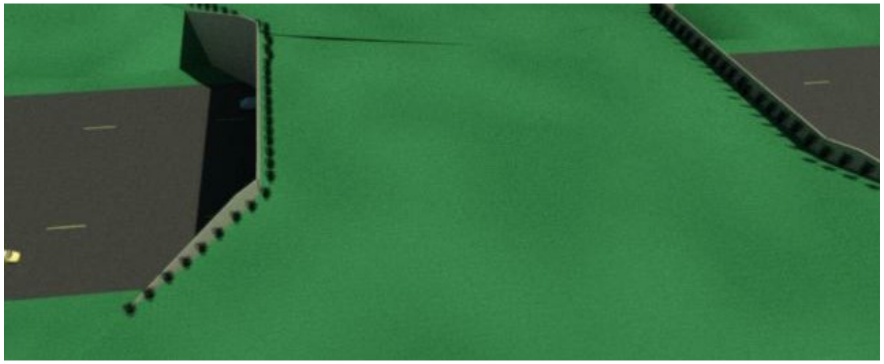
1 RENDERING LOOKING NORTH
12" = 1'-0"

WPI	MQP 2019 WILDLIFE CROSSING BRIDGE	DATE: 9/30/2019
	RENDERING LOOKING NORTH	DRAWN BY: LB, HG, SL, MO

Revit Page 5



1 RENDERING - CROSSING VIEW
6" = 1'-0"



2 RENDERING - CROSSING VIEW 2
6" = 1'-0"

WPI	MQP 2019 WILDLIFE CROSSING BRIDGE	DATE: 9/30/2019
	RENDERINGS – CROSSING	DRAWN BY: LB, HG, SL, MO

5.0 Conclusions

Over the course of eight weeks, the team designed a wildlife overpass to be implemented over Highway 1 in conjunction with el Instituto de campo Batipa (BFI) and Universidad Tecnológica Oteima (UTO), programs run by Fundación Batipa. Developing this wildlife crossing contributed to both organization's efforts towards biodiversity preservation and sustainability. The team worked alongside Dr. Francisco Ugel of UTO and the coordinator of BFI, Edmundo Gonzalez, in order to understand the problem from those who have experienced it firsthand, and come up with a feasible solution to issues of roadkill, habitat fragmentation, and local misunderstanding. With the final overpass design in hand, it is the hope that UTO will have the opportunity to pitch the project to potential sponsors for funding and to the Panamanian government for permission to move forward with construction. Not only will the construction of this overpass help hundreds of animal species living in Batipa by providing a safe way to cross the four-lane highway, it will also be great exposure for BFI. Since BFI is a very new organization, it could be very beneficial to have this large infrastructure project near their entrance, which will be seen by the hundreds of travelers on the highway who will wonder the significance of the crossing. This could be a great way to educate people on the importance of biodiversity and wildlife preservation.

The work completed during this project was not only beneficial to the stakeholders within Panama, but the experience was also crucial to the team's undergraduate education. Through structural analysis of bridge members, the team was able to apply their engineering knowledge to a real-world problem, thus strengthening their skills. In addition, the project fulfilled the requirements of WPI's design criteria for the Accreditation Board for Engineering and Technology and heightened the group members abilities to work as a team and collaborate with professionals in the field.

Capstone Design Statement

The Major Qualifying Project (MQP) at Worcester Polytechnic Institute (WPI) serves to fulfil the capstone design requirements of the Accreditation Board for Engineering and Technology (ABET). The purpose of this capstone design experience is for students to complete an engineering design project that incorporates real life constraints including ethics, environmental implications, and sustainability. The completion of the MQP represents a cumulative project based on the knowledge and skills gained throughout the undergraduate curriculum.

Engineers must uphold the principles of ethics in order to ensure the welfare and safety of everyone who may be involved in any stage of a project. Although the wildlife crossing in this project was designed to be constructed in Panama, The Code of Ethics of the American Society of Civil Engineers (ASCE) was followed carefully in regards to safety, professionalism, quality, and equality. Throughout the design process, the lives of those affected by the proposed crossing were incorporated into the structure through sustainable material selection and a design with the fewest construction and maintenance requirements in order to keep the major highway active. In addition, in conjunction with following ASCE code of ethics, the project team was fully transparent with stakeholders during all steps of the design process, worked diligently to produce the best results, and treated all persons with respect and fairness. The social impacts of the project drove the thought process behind every design decision, since the bridge bypasses the most traveled highway in the country in an area that splices together the populations of 115 animal species.

The construction of the wildlife crossing over the Pan-American Highway could have extremely detrimental impacts on the delicate surrounding ecosystem if not done properly. Erosion control measures are key to ensuring that the soil of the surrounding environment is not depleted of its nutrients or contaminated with foreign material run-off. In order to protect the soil's integrity around the structure, vetiver, a natural erosion preventer, was proposed to be planted strategically on the crossing. In addition to soil concerns, the design of the bridge accommodates the area's natural hydrological patterns and has fencing to protect wildlife from getting off the structure and hurting themselves. Because Batipa is part of a larger biological corridor that extends from the mountains of Gualaca to the coast of the Gulf of Chiriqui, and Panama as a whole is part of the larger Mesoamerican biological corridor, there are many species of plants and animals that could be at risk from inappropriate design and construction tactics.

Another consideration for engineers to think about that is outlined by the ASCE code of ethics is the long-term implications of a project and whether the structure will be able to sustain itself overtime. An important aspect of the wildlife crossing over Highway 1 to ensure long-term sustainability was to populate the structure with native species that would naturally develop overtime, making the bridge not only an engineering structure, but an extension of the natural environment. In addition, the crossing was designed with few long-term maintenance requirements, minimal excavation and disturbance of the natural environment during construction, and use of sustainable materials such as concrete.

Professional Licensure Statement

Although this project delivers a completed wildlife crossing design, the successful construction and implementation of this bridge would require the work of Professional Engineers (PEs) to ensure safety and structural reliability. PEs are engineers that have proven their high-level of competency in the field both in terms of skill and ethics in order to obtain their professional licensure. Licensure refers to an official procedure carried out by a state-level authority of which is required for a person to practice a regulated profession. In 1907, the first engineering licensure law was enacted in Wyoming in order to regulate the practice and ensure public safety through the guarantee of competent engineers. Since then, every state has adopted regulation of engineering based on discipline.

In order to obtain a civil engineering licensure, a person must dedicate a number of years of hard work to completing four main steps. The first step is earning a four-year degree in engineering from an accredited engineering program. Next, the individual must pass the Fundamentals of Engineering (FE) exam. The FE is a 6-hour, 110 question, computer-based test designed for recent graduate students or students currently completing their undergraduate education. It can be taken as either a generic engineering exam or for a specific discipline (i.e. chemical, civil, environmental), but always consists of an extremely broad range of topics from calculations with equations to key concept explanations. The third step to obtaining an engineering licensure is to complete four years of engineering experience under one or more qualified engineers in the branch in which the candidate claims proficiency. This experience must be high-level enough to require the individual to develop technical skill and show initiative in advancing their engineering development. The final step to obtaining licensure and becoming a Professional Engineer is to pass the Principles and Practice of Engineering (PE) exam. The PE exam is an 8-hour, pen and paper exam with 80 questions. For civil engineers, the exam can be taken for one of the five following disciplines: construction, geotechnical, structural, transportation, or water resources and environmental. After passing this exam, the candidate has successfully completed the process of obtaining their professional licensure, but it doesn’t end there. In order to maintain the licensure, many states require PEs to continually improve their skills through education programs and professional development.

Through the process of getting and maintaining licensure, engineers prove their skillset and dedication to quality engineering. The reason for this extensive process comes with the weight of the decisions that PEs have the ability to make and are required to make. Only a licensed engineer may prepare, sign and seal, and submit proposed engineering plans for approval or seal engineering work themselves for clients. Their approval ensures that the structure is ethical, safe, and completely ready to be constructed. This MQP replicates the professional practice of a licensed engineer by solving a complex design problem that addresses real world conditions and constraints, however PEs would be needed to approve all drawings, structural calculations, and the overall design to ensure its safety before proceeding with construction.

Bibliography

[1] J. F. Rippy, "The Inter-American Highway," *Pacific Historical Review*, vol. 24, no. 3, pp. 287–298, 1955.

[2] "Latin America," *The Nature Conservancy*. [Online]. Available: https://www.nature.org/en-us/about-us/where-we-work/latin-america/. [Accessed: 16-Jul-2019].

[3] "The IUCN Red List of Threatened Species," *IUCN Red List of Threatened Species*. [Online]. Available: https://www.iucnredlist.org/en. [Accessed: 16-Jul-2019].

[4] Lonely Planet, "Land & Wildlife in Panama," *Lonely Planet*. [Online]. Available: https://www.lonelyplanet.com/panama/background/other-features/5bb59be8-14c0-42a3-8cc9-6f0cfd64d46b/a/nar/5bb59be8-14c0-42a3-8cc9-6f0cfd64d46b/358509. [Accessed: 16-Jul-2019].

[5] Panama Wildlife Conservation, "Panama Wildlife Conservation," *Panama Wildlife Conservation*. [Online]. Available: https://panamawildlife.org/about-panama/. [Accessed: 19-Jul-2019].

[6] Government of New South Wales Office of Environment & Heritage, "Wildlife Cooridors." Department of Infrastructure, Planning, and Natural Resources, 08/04.

[7] "Wildlife Crossing Structure Handbook Deisgn and Evaluation in North America." U.S. Department of Transportation, 03/11.

[8] J. Sabatini, "Improved Animal Crossings Show a Huge Decline in Wildlife Collisions," *Car and Driver*, 07-Aug-2018. [Online]. Available: https://www.caranddriver.com/features/a22654629/these-animal-crossings-show-decline-in-wildlife-collisions. [Accessed: 19-Jul-2019].

[9] E. Gonzales, "Interview with Head of BFI Research Center."

[10] "Giras Ecoturísticas | Giras Académicas | Batipa." [Online]. Available: https://batipafieldinstitute.com/en/. [Accessed: 16-Jul-2019].

[11] Z. Guo, L. Zhang, and Y. Li, "Increased Dependence of Humans on Ecosystem Services and Biodiversity," *PLOS ONE*, vol. 5, no. 10, p. e13113, Oct. 2010.

[12] A. Slingenberg, L. Braat, H. van der Windt, K. Rademaekers, L. Eichler, and K. Turner, "Study on understanding the causes of biodiversity loss and the policy assessment framework," Eurpoean Commission Directorate-General for Environment, Oct. 2009.

[13] Thos. G. Scott, "Wildlife Mortality on Iowa Highways," *The American Midland Naturalist*, vol. 20, no. 3, pp. 527–539, 1938.

[14] O. Chassot, A. Valverde, V. Jiménez, E. Müller, and T. Moreno, "Regional report for Mesoamerica," p. 98, May 2012.

[15] S. W. Miller, "Minding the Gap: Pan-Americanism's Highway, American Environmentalism, and Remembering the Failure to Close the Darién Gap," *Enviro Hist Durh N C*, vol. 19, no. 2, pp. 189–216, Apr. 2014.

[16] G. of C. Parks Canada Agency, "Mountain Wildlife - Banff National Park," 02-Apr-2017. [Online]. Available: https://www.pc.gc.ca/en/pn-np/ab/banff/decouvrir-discover/faune-wildlife. [Accessed: 16-Jul-2019].

[17] "Panama Information: Guide to Panamanian History." [Online]. Available: https://www.anywhere.com/panama/travel-guide/history. [Accessed: 06-Sep-2019].

[18] "Culture of Panama - history, people, women, beliefs, food, customs, family, social, dress." [Online]. Available: https://www.everyculture.com/No-Sa/Panama.html. [Accessed: 16-Jul-2019].

[19] Panama Relocation Tours, "'See' Panama Before You Get There," *Panama Relocation Tours*, 07-Jul-2011. [Online]. Available: https://panamarelocationtours.com/see-panama-before-you-get-there. [Accessed: 19-Jul-2019].

[20] "Central America :: Panama — The World Factbook - Central Intelligence Agency," 02-Jul-2019. [Online]. Available: https://www.cia.gov/library/publications/the-world-factbook/geos/pm.html. [Accessed: 16-Jul-2019].

[21] S. Mufson, "An expanded Panama Canal opens for giant ships - The Washington Post," *The Washington Post*, 26-Jun-2016. [Online]. Available: https://www.washingtonpost.com/world/the_americas/an-expanded-panama-canal-opens-for-giant-ships/2016/06/26/11a93574-37d1-11e6-af02-1df55f0c77ff_story.html?noredirect=on&utm_term=.8218d7c396b3. [Accessed: 16-Jul-2019].

[22] Bozeman, "MSU's Western Transportation Institute featured for research on wildlife crossings," *Montana State University*, 11-Jan-2018. [Online]. Available: http://www.montana.edu/news/17385/msu-s-western-transportation-institute-featured-for-research-on-wildlife-crossings. [Accessed: 16-Jul-2019].

[23] S. Dettman, "The Mesoamerican Biological Corridor in Panama and Costa Rica: Integrating Bioregional Planning and Local Initiatives," *Journal of Sustainable Forestry*, vol. 22, no. 1–2, pp. 15–34, May 2006.

[24] "Conservation Milestones in Panama," 2019. [Online]. Available: https://www.nature.org/en-us/about-us/where-we-work/latin-america/panama/panama-conservation-milestones/. [Accessed: 16-Jul-2019].

[25] "Misión, Visión y Valores," *Universidad Tecnológica Oteima*. [Online]. Available: http://www.oteima.ac.pa/oteima/mision-vision-y-valores-2-2/. [Accessed: 16-Jul-2019].

[26] T. Cloutier, A. Konsko, D. Palermo, and J. Scammon, "Sustainable Design Solutions for Batipa Field Institue," Worcester Polytechnic Institute, Oct. 2017.

[27] "The Pan American Highway: The Longest Road In The World," *Brilliant Maps*. [Online]. Available: https://brilliantmaps.com/pan-american-highway/. [Accessed: 16-Jul-2019].

[28] S. Vartan, "How wildlife bridges over highways make animals—and people—safer," *National Geographic*, 16-Apr-2019. [Online]. Available: https://www.nationalgeographic.com/animals/2019/04/wildlife-overpasses-underpasses-make-animals-people-safer/. [Accessed: 16-Jul-2019].

[29] "Connecting Wildlife Habitats," *National Wildlife Federation*, 03/. [Online]. Available: https://www.nwf.org/Home/Our-Work/Habitats/Wildlife-Corridors. [Accessed: 16-Jul-2019].

[30] S. Holder, "Build More Animal Bridges!," *CityLab*, 31-Jul-2018. [Online]. Available: https://www.citylab.com/life/2018/07/wildlife-crossings-bridges-tunnels-animals-roads-highways-roadkill/566210/. [Accessed: 16-Jul-2019].

[31] "Average Weather in Chiriquí, Panama, Year Round - Weather Spark," 2019. [Online]. Available: https://weatherspark.com/y/16722/Average-Weather-in-Chiriqu%C3%AD-Panama-Year-Round. [Accessed: 16-Jul-2019].

[32] "David, Panama - Detailed climate information and monthly weather forecast," *Weather Atlas*, 2019. [Online]. Available: https://www.weather-atlas.com/en/panama/david-climate. [Accessed: 16-Jul-2019].

[33] M. C. Larsen and A. S. Román, "Mass wasting and sediment storage in a small montane watershed: An extreme case of anthropogenic disturbance in the humid tropics," in *Water*

Science and Application, vol. 4, J. M. Dorava, D. R. Montgomery, B. B. Palcsak, and F. A. Fitzpatrick, Eds. Washington, D. C.: American Geophysical Union, 2001, pp. 119–138.
[34] S. Sanguankaeo, C. Sukhawan, and E. Veerapunth, *The Role of Vetiver Grass in Erosion Control and Slope Stabilization Along the Highways of Thailand*. .
[35] Teak Hardwods, “Precious Teakwood: What you need to know.” .
[36] “Your Guide to Understanding the World of Teak Investments.” teak hardwoods.
[37] A. Evans, “The Alberta Story: Wildlife Crossing in Banff,” *National Geographic*, 23-Aug-2013. [Online]. Available: https://www.nationalgeographic.com/travel/digital-nomad/2013/08/23/the-alberta-story-wildlife-crossing-in-banff/. [Accessed: 16-Jul-2019].
[38] A. Clevanger and M. Barrueto, “Trans-Canada Highway Wildlife Monitoring and Research, Final Report. Part B: Research.,” Parks Canada Agency, Radium Hot Springs, Bristish Columbia, Jun. 2014.
[39] P. S. Gilhooly, S. E. Nielsen, J. Whittington, and C. C. S. Clair, “Wildlife mortality on roads and railways following highway mitigation,” *Ecosphere*, vol. 10, no. 2, p. e02597, 2019.
[40] M. Renard, A. A. Visser, W. F. de Boer, and S. van wieren, “The use of the ‘Woeste Hoeve’ wildlife overpass by mammals.,” *Lutra*, vol. 51, pp. 67–90, Jan. 2008.
[41] D. Veerman, “De A50 Ecoducten | Dick Veerman,” 02-Jan-2011. .
[42] “Saving Animals, The Compton Roadd Effect,” *Griffith University*. [Online]. Available: https://www.griffith.edu.au/research/impact/compton-road-wildlife-corridor. [Accessed: 16-Jul-2019].
[43] AASHTO, “Section 8: Concrete Structures,” in *AASHTO LRFD Bridge Construction Specifications*, 3rd ed., American Association of State Highway and Transportation Officials (AASHTO), 2012, pp. 8.1-8.64.
[44] AASHTO, “Section 9: Reinforcing Steel,” in *AASHTO LRFD Bridge Construction Specifications*, 3rd ed., American Association of State Highway and Transportation Officials (AASHTO), 2012, pp. 9.1-9.8.
[45] *AASHTO LRFD BRIDGE DESIGN SPECIFICATION: Customary U.S. Units 2012*, Part 1: Sections 1-6. Washington, DC: AASHTO, 2012.
[46] American Society of Civil Engineers, “Chapter 26 Wind Loads: General Requirements,” in *Minimum Design Loads for Buildings and Other Structures, Standard ASCE 7*, 2013, pp. 187–201.
[47] American Society of Civil Engineers, “Chapter 27 Wind Loads on Buildings- MWFRS (Directional Procedure),” in *Minimum Design Loads for Buildings and Other Structures, Standard ASCE 7*, 2013, pp. 203–238.
[48] F. A. Charney, *Seismic Loads: Guide to the Seismic Load Provisions of ASCE 7-10*. Reston, VA: American Society of Civil Engineers, 2014.
[49] K. C. Mehta and W. L. Coulbourne, *Wind Loads: Guide to the Wind Load Provisions of ASCE 7-10*. Reston, UNITED STATES: ASCE, 2013.
[50] J. Gutiérrez, “Reglamento de Diseño Estructural para la República de Panamá (REP-2003). Chapter 4- Seismic Loads.” 2003.
[51] P. E. Roger Brockenbrough and P. E. Frederick S. Merritt, “ARCH BRIDGES,” in *Structural Steel Designer’s Handbook, Fifth Edition*, 5th ed., New York: McGraw-Hill Education, 2011.
[52] Barry R. Christopher, Ph.D., P.E., Charles Schwartz, Ph.D., P.E., and Richard Boudreau, P.E., “Geotechnical Aspects of Pavements,” National Highway Institute U.S. Department of

Transportation Federal Highway Administration, Washington, D. C., FHWA NHI-05-037, May 2006.
[53] Michael A. Grubb, P.E., Kenneth E. Wilson, P.E., S.E., Christopher D. White, P.E., and William N. Nickas, P.E., "Load and Resistance Factor Design (LRFD) for Highway Bridge Superstructures - Reference Manual," Federal Highway Administration National Highway Institute (HNHI-10), Arlington, VA, FHWA-NHI-15-047, Jul. 2015.
[54] Jeremy Hung, PE, James Monsees, PhD, PE, Nasri Munfah, PE, and John Wisniewski, PE, "Technical Manual for Design and Construction of Road Tunnels- Civil Elements," National Highway Institute U.S. Department of Transportation Federal Highway Administration, Washington, D. C., FHWA-NHI-09-010, Mar. 2009.