Analysis of National Bridge Inventory (NBI) Data for California Bridges

By

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Abstract

The National Bridge Inventory (NBI), managed by the Federal Highway Administration (FHWA), is an untapped source of data that accounts for all the bridges and tunnels that are more than 20 feet in length within the United States. It records significant data regarding bridge properties which include: roadway classification, geographic location, age, material, structure type and others. Although the data has been studied briefly in some research, in depth analysis for specific states has not been performed.

The objective of this research is to understand the NBI data structure and its limitations; retrieve, organize, and analyze bridge data, and provide meaningful information on bridge properties and performance. This research will focus on bridges in California, with an emphasis in Southern California counties around and including Los Angeles such as Kern, Los Angeles, Orange, Riverside, San Bernardino, San Diego, and Ventura counties. Trends and correlations will be drawn from data analysis and statistical comparisons. It is expected that a correlation between bridge performance and its properties will be established. Relationships between bridge performance in California in terms of strength and serviceability will also be examined.

The data for this analysis is provided by the NBI, which is available through the FHWA website, the National Bridges website, which is an online database search engine that is based on data from the NBI and information from the Department of Transportation for each state, and the Department of Transportation website.
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1. Introduction

The National Bridge Inventory (NBI) is a continuously growing database that accounts for all the bridges and tunnels within the United States. The Federal Highways Administration (FHWA) defines a bridge as “A structure including supports erected over a depression or an obstruction…and having an opening measured along the center of the roadway of more than 20 feet.” (National Bridge Inspection Standards). Managed by the FHWA, the NBI provides a span of information regarding bridge properties over decades which include: roadway classification, geographic location, age, material, structure type and others. The result is a vast database that hosts significant data regarding bridge properties. However, the potential of the database has been limited because there is little research on the NBI database that could reveal information, trends, and correlations hidden behind the immense amount of data. Although the data has been studied briefly from the whole country standpoint in some research, an in depth analysis for specific states has not been performed.

This investigation is aimed at understanding and investigating the National Bridge Inventory (NBI) database and retrieving, organizing and analyzing information provided for the state of California. The purpose of the analysis is to provide meaningful information to a limitless amount of data that is valueless if left unanalyzed. The information on bridge properties and performance, as well as patterns and trends presented in this report are considered essential to users, owners, maintenance and inspection agencies, as well as, designers.

Within the United States there is a total of 610,749 bridges, and of those, 25,406 bridges are within California [NBI, 2014]. This research will focus on the 25,406 bridges in California, and primarily those in Southern California including those in Kern, Los Angeles, Orange, Riverside, San Bernardino, San Diego, and Ventura counties, which account for 39% of the total bridges in California.

Trends and correlations will be drawn from data analysis and statistical comparisons. It is expected that a correlation between bridge performance and its properties will be established. Relationships between bridge performance in California in terms of strength and serviceability will also be examined.
1.1. Research Methodology

The data for this analysis is primarily provided by the National Bridge Inventory (NBI), which is available through the FHWA website. The reason why the first step of this investigation is to focus on understanding the NBI database is because the majority of the information in the database is in html or excel format. Comprised of large datasets, the NBI information can found in the ASCII files. The NBI is an untapped source of data; indeed, the NBI record for a single bridge contains more than 115 attributes or parameters associated with that bridge including age, location material and others, which are updated with time and collected in the database. Getting information from the NBI database, other than the one provided on the FHWA website, requires developing a search engine or using an existing search engine. National Bridges is a search engine that uses compiled data from the NBI and information from the Department of Transportation for each state. This search engine is particularly useful in that it is designed so that it can provide a number of bridge attributes at different levels, for instance at route and at county level. The National Bridges search engine is the other source of data for this research. The information that is to be extracted in this research includes bridge count and deck area and the corresponding parameters to be analyzed. These parameters include: material composition, wearing surface and deck protection, age, functional system, structural status, average daily traffic, attributes at route level and county level, ownership, and unit cost.

The most recent data of the National Bridge Inventory is used in this research, this is NBI 2014. It is to be noted that the last update for some of the information within the National Bridges database corresponds to year 2012. However, given that the most recent version of National Bridges is based on the NBI 2012, it is thought that using data from the NBI 2014 and the National Bridges database should not cause drastic deviations.

Once the NBI database is understood, the data is explored and relevant information is extracted from the NBI database, either directly or through the National Bridges search engine, into excel files. The information is then analyzed and interpreted using data visualization techniques, which includes graphical and tabular presentations. This technique aids in understanding the meaning of the data and discovering trends and relationships that otherwise would be impossible to discover, given the raw format and the size of the NBI database.
1.2. Literature Review

An in-depth analysis of the National Bridge Inventory (NBI) database has been scarce. Several researchers have used the NBI to conduct investigations of the functionality of bridges in the United States as a whole country (Wu 2010, Chase et al. 1995, Lee 2012), while a report (Bridge Division, Texas DOT 2014) concentrated on data from the NBI for bridges in the state of Texas.

Research by Wu (2010), accounted for a range of data from the NBI for all the states. The methodology includes using exploratory data analysis of the data with both a geographic information system (ArcGIS) and a computing application (Matlab). The bridge parameters accounted for in the research include location, average daily traffic, structure length, deck width, structure type, ownership, maintenance responsibility, bridges design, environmental impacts, and critical bridges. The research showed the condition of bridges by state. Research results seem to indicate that bridges in the eastern side of the United States are generally designed with lower design load standards, that there is a significant increase of design load of bridges over time, and that there are many temporal patterns found for deficiency, structure, and design load types.

Chase et al. (1995) used the NBI data to create regression models linked to environmental variables to predict condition ratings of bridges. The bridge parameters used in this research include age, average daily traffic, and material composition. Additionally, the research focuses on environmental effects of precipitation, temperature range, and freeze thaw cycles on bridges deterioration. A geographic information system is used to link environmental and natural hazard variables and the NBI data. Research results seem to indicate that regression models could be used to predict the deterioration of bridge decks, superstructures, and substructures.

Lee (2012) analyze the NBI data and determine cause of deterioration in bridges. The bridge parameters accounted for in this research were traffic volume, structure type and deck protection systems, material type and age. Research results seem to indicate that bridge age, span length, average daily traffic and location and highway system, among other parameters, may have an effect on structural deficiency potential.

The study by Bridge Division, Texas DOT Report (2014), unlike other studies, focuses on the condition of publicly owned bridges in Texas. The report uses the NBI to access the change in the condition of bridges from 2004 to 2014. The report documents bridge parameters such as age,
distribution location and highway system, the change of bridge conditions over time, and the bridge funding distribution. The results of the study indicate a growing count of bridges in Texas, and an increased quality with most of the bridge funding been spent in bridge rehabilitation and replacement.

### 1.3. Bridge Distribution in the United States

Bridge population analysis is based on both count of bridges and bridge area. There is a total of 610,749 bridges that cover 3,934,665,828.5 square feet in the United States. Figure 1 and Figure 2 depict the distribution of bridge count and bridge area, respectively, in the United States.

As shown in Figure 1, Texas has the largest bridge population within the United States, accounting for nearly 9% of total bridges, followed by Ohio, with 4.42% of total bridges, and Illinois, with 4.35% of total. Texas has a total of 52,937 bridges which covers 23,812,360 square feet. Bridges in Texas also cover the most area as shown in Figure 2.

Figure 1 indicates that California has the fourth largest bridge population (4.2%) in the nation with a total of 25,406 bridges. However, contrary to this, Figure 2 demonstrate that the area of California bridges is the second largest (7.9%) in the nation, with its bridges covering a total of 311,674,503 square feet. California is followed by Louisiana, whose bridges cover 70,115,328 square feet, and Florida, whose bridges cover 40,510,942 square feet. This trend indicates that results per count are not always representative of the bridge distribution.
Figure 1: Distribution of bridge count in the United States represented by percentage of total bridge count [NBI 2014]
United States Bridge Distribution Represented by Percentage of Total Area

Figure 2: Distribution of bridge area in the United States represented by percentage of total bridge area [NBI 2014]
1.4. Southern California Counties

In California, there are 58 counties and 25,406 bridges [NBI 2014]. The majority of the California bridges listed within the NBI are managed by CalTrans, the California Department of transportation. CalTrans owns 49% of California bridges. This research has an emphasis on seven counties around the city of Los Angeles: Kern, Los Angeles, Orange, Riverside, San Bernardino, San Diego, and Ventura (See Figure 3). These counties account for 39% of the bridges in California, as shown in Figure 4.

Larger bridge populations indicate higher development and population within those counties. Of the seven counties, the Los Angeles County has the highest count of bridges in the state. As one of the largest and highly populated counties in California, the Los Angeles County accounts 14% of the bridges in California, followed by San Diego accounting for nearly 6% of California’s bridges and San Bernardino and Orange with nearly 5%.
Material composition is an important aspect in analyzing the longevity of bridges and seeing which is more cost effective and practical for the allotted time the bridge is in service.

Concrete bridge composition includes bridges such as, concrete single span, concrete continuous, pre-stressed concrete single-span, and pre-stressed concrete continuous. Steel bridges include steel single-span and steel continuous material compositions. “Other” includes bridges that are composed of wood, masonry, iron, and other materials.
The majority of the bridges in the United States are composed of either concrete or steel. As shown in Figure 7, nearly 66% of the bridges in the United States are composed of concrete and 30% are composed of steel. Bridges composed of other materials are very scarce compared to steel and concrete. Only 4% of bridges in the United States are composed of wood, masonry, iron, and other materials.

![Figure 7: Material composition of United States bridges represented by percentage of total bridge count [NBI 2014]](image)

Following the trend in Figure 7, it is clear that concrete is dominant in bridge construction in the United States. When analyzing bridges from different states, concrete seems to be the leading material used, as shown in Figure 8 and Figure 9. However, in select states such as Maine, New York, Michigan, New Jersey, and Maryland, bridges do not follow this general trend. In these states, there are substantially more steel than concrete bridges.

As shown in Figures 8 and 9, Texas is shown to have the highest count and area of concrete bridges compared to other states. Texas accounts for 7% of the count and 9% of the area of concrete bridges in the United States. Following Texas, California is the state with the highest concrete bridge population, as well as, the highest concrete bridge area. California has 21,497 concrete bridges, which is 3.5% of the total bridge count in the United States. Compared to its bridge count, bridges in California account for nearly twice the bridge count percentage, with 6.7% of total bridge area in the United States.
Figure 8: Material composition of United States bridges represented by count [NBI 2014]
Figure 9: Material composition of United States bridges represented by area [NBI 2014]
In depth analysis indicates that bridges located in California are not exempt from the pattern shown from the material distribution of bridges in the United States. A total of 21,758 bridges (86% of California bridges) are constructed from concrete, 2,856 bridges (11% of California bridges) are composed of steel and 792 bridges (3% of California bridges) are composed of other materials, as shown in Figure 10, which depicts the count of bridges per material composition in California. A study of the area of bridge distribution per material indicates a similar trend. 85% of the total area of bridges in California is concrete, 14% is steel, and 1% is other materials, as shown in Figure 11.

*Figure 10: Material composition of California bridges represented by percentage of bridge count [NBI 2014]*
2.1. Southern California Counties

In Southern California, the primary material used for the construction of bridges is concrete. Steel and other materials are also used, however it is not as common. As shown in Figure 12, the number of concrete bridges in each county is nearly 10 times the number of steel bridges and nearly 90 times the other material bridges in the same county.

Table 1, below, indicates the material distribution of all of the bridges in Southern California counties in percentage of bridge count. Results indicate that San Bernardino’s bridges have the most material diversity. Compared to San Bernardino, Orange County’s bridges has the least diversity, with the majority of its bridges composed of concrete.
Table 1: Distribution of bridge material per count in Southern California counties

<table>
<thead>
<tr>
<th>County</th>
<th>Concrete (%)</th>
<th>Steel (%)</th>
<th>Other (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>San Diego</td>
<td>96.4</td>
<td>3.0</td>
<td>0.6</td>
</tr>
<tr>
<td>Orange</td>
<td>95.1</td>
<td>4.6</td>
<td>0.3</td>
</tr>
<tr>
<td>Riverside</td>
<td>94.5</td>
<td>4.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Ventura</td>
<td>93.3</td>
<td>5.4</td>
<td>1.3</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>92.8</td>
<td>6.8</td>
<td>0.4</td>
</tr>
<tr>
<td>Kern</td>
<td>90.1</td>
<td>8.5</td>
<td>1.4</td>
</tr>
<tr>
<td>San Bernardino</td>
<td>84.5</td>
<td>9.7</td>
<td>5.8</td>
</tr>
</tbody>
</table>

Figure 12: Material distribution of Southern California Bridges [National Bridges-NBI 2012]

3. Bridge Wearing Surfaces and Deck Protection

Measures to protect bridges from environmental and external factors include adding wearing surfaces and deck protection to bridges. Wearing surfaces are materials that cover bridges and provide skid resistance and wear-resistance (Aboutaha). Deck Protection is used to prevent corrosion damage to reinforcement (Andrade and Holst, 1995).
Figure 13 shows the distribution of bridges with wearing surfaces in the United States. 455,094 bridges (88% of the total number of bridges in the United States) have wearing surfaces.

![Pie chart showing the distribution of wearing surfaces among bridges in the United States.](image)

*Figure 13: United States bridges with wearing surfaces represented by percentage of bridge count [NBI 2014]*

Wearing surfaces are documented within the NBI under nine different categories: monolithic concrete, integral concrete, latex concrete, low slump concrete, epoxy overlay, wood or timber, gravel, other, and bituminous wearing surfaces. Within this report, wearing surfaces have been grouped in three different categories. The first category combines all of the concrete wearing surfaces, which include monolithic integral, latex, and low slump concrete. The second category is bituminous wearing surfaces. The third category combines epoxy overlay, wood or timber, gravel, and other wearing surfaces.

Within the United States, the majority of the bridges with wearing surfaces are composed of monolithic, integral, latex, and low slump concrete, as shown in Figure 14. A total of 210,366 bridges (46% of United States bridges with wearing surfaces) have the concrete wearing surface. The second most predominant wearing surface is bituminous, which covers 185,424 bridges (41% of United States bridges with wearing surfaces). 59,304 bridges (13% of United States bridges with wearing surfaces) have epoxy overlay, wood or timber, gravel, or other material wearing surfaces.
When analyzing the area, it was discovered that the amount of area monolithic, integral, latex, and low slump concrete cover accounts for much more of the total area of United States bridges with wearing surfaces compared to the total count for United States bridges with wearing surfaces. As shown in Figure 15, monolithic, integral, latex, and low slump concrete accounts for 69% of the total area of bridges with wearing surfaces. Bituminous surfaces and epoxy overlay, wood or timber, gravel, and other wearing surfaces account for much smaller area. Bituminous surfaces only cover 25% of United States bridges with wearing surfaces and epoxy overlay, wood or timber, gravel, and other wearing surfaces cover 6% of United States bridges with wearing surfaces.

*Figure 14: Wearing surfaces of United States bridges represented by percentage of bridge count [NBI 2014]*
In California, 13,091 (58%) of bridges have a form of wearing surface, as shown in Figure 16. This follows the trend shown in bridges throughout the United States.

In California, nearly 5,033 (38% of total wearing surfaces) of bridges have concrete wearing surfaces, 7,437 (57% of total wearing surfaces) of bridges have bituminous wearing surfaces, and
621 (5% of total wearing surfaces) of bridges have epoxy overlay, wood or timber, gravel, or other wearing surfaces, as shown in Figure 21. The bituminous wearing surfaces have the highest count on bridges. Figure 22, however, which depicts wearing surface in percentage of bridge area, shows that bituminous wearing surface covers the least bridge area in California. This figure indicates that concrete wearing surface covers the most of bridge area. As a matter of fact, concrete wearing surfaces covers 66% of total wearing surface area, followed by epoxy overlay and other with 30%, and bituminous surfaces with only 4%.

Figure 17: Wearing surfaces of California bridges represented by percentage of bridge count [NBI 2014]
In the United States, 161,736 bridges have deck protection, which is equivalent to 32% of the bridges in the United States. As shown in Figure 19, the majority of the bridges in the United States do not have deck protection.

Figure 18: Wearing surfaces of California bridges represented by percentage of bridge area [NBI 2014]

Figure 19: United States bridges with deck protection represented by percentage of bridge count [NBI 2014]
In regards to deck protection, there are seven different types recorded in the NBI. They include epoxy coated reinforcing, polymer impregnated, galvanized reinforcing, cathodic protection, internally sealed, other coated reinforcing, “unknown”, and other deck protections.

The most used deck protection in the United States is the epoxy coated reinforcing, as shown in Figure 20. There 82,830 bridges (51% of United States bridges with deck protection) with epoxy coated reinforcing deck protection. 71,456 bridges (44% of United States bridges with deck protection) have unknown deck protection.

Figure 21, shows that there is a correlation in deck protection count and deck protection area. Epoxy coated reinforcing accounts for the majority of the area of United States bridges with deck protection.

![Pie chart showing deck protection types](image-url)

*Figure 20: Deck protection of United States bridges represented by percentage of count [NBI 2014]*
Only 358 bridges (2%) of the California bridge population have deck protection, as shown in Figure 22.

Deck protection is scarce over the California bridge population, as mentioned earlier. Figure 23 shows that the deck protection per count of bridges that is most widely used in California is...
epoxy-coated reinforcing. There are 201 bridges (56% of total bridges with deck protection) that have this deck protection. The second most used deck protection is the polymer impregnated deck protection which accounts for 44 bridges (13% of the total bridges with deck protection). However, when analyzing the area of bridges with deck protection (Figure 24), polymer impregnated deck protection covers much more bridge surface than epoxy coated reinforcing. Polymer impregnated deck protection covers 46% of the total area of bridges with deck protection while epoxy coated reinforcing only covers 26% of the total area of bridges with deck protection.

Bridges in California, unlike the trend shown in the deck protection of United States bridges, have a large population of bridges with polymer impregnated deck protection. Of the bridges in the United States that have deck protection, only 1% of the bridge count has polymer impregnated deck protection. However, in California, 13% of the bridges with deck protection has a polymer impregnated deck protection.

Figure 23: Deck protections of California bridges represented by percentage of bridge count [NBI 2014]
Age

The average lifespan of bridges is approximately 70 years neglecting environmental and external deterioration factors. However, environmental and external factors, which are unavoidable, lower the lifespan of bridges to 50 years. Many of the bridges in the United States are either approaching 50 years old or have exceeded that age, indicating the higher probability of deterioration and deficiency.

As shown in Figure 25, there was a major increase in bridge population from 1949-1968. Between 1964-1968, the number of bridges built in that time span peaked, leading to the construction of 8.67% of the total bridge population or 52,727 bridges. Since then, the number of bridges that have been constructed have not exceeded 52,727. In the more recent years, there has been a gradual decrease in the trend of number of bridges built each year.

As shown in Figure 26, the area of the bridges constructed began to increase rapidly in 1944-1948 and a general decreasing trend in the years following its peak in 1969-1973. The highest count of bridges built occurred in 1964-1968, however, in 1969-1973 the most bridge area was constructed. The bridges in 1969-1973 accounted for more bridge area per bridge, indicating larger
bridges were constructed in this time period. Generally, the bridge area correlated directly to the pattern of the count of bridges built each year.

Figure 25: Age of United States bridges represented by percentage of total bridge count [NBI 2013]
Although construction of bridges in California do not follow the exact national trend of the number of bridges built each year, California bridges follow a similar pattern. As shown in Figure 27, the number of bridges built each year follows a bell shaped pattern where the number of bridges increase gradually until it peaks, then decreases gradually. The number of bridges built peaks in 1964-1968, where the number of bridges constructed was 3,886 bridges (15.5% of total California bridges). The peak in the number of California bridges constructed occurs at the same time where the construction of the number of United States bridges peaks.
Concrete Bridges

The construction of concrete bridges in California follow the same bell trend of the construction of all California bridges, as shown in Figure 28. The number of concrete bridges constructed peaks in 1964-1968 with the construction of 3,504 concrete bridges, which is equivalent to 16.3% of California’s concrete bridges.

From 1908 and earlier to 1964-1968, where the number of concrete bridges constructed peaks, there is a gradual increase in concrete bridge construction in California. However, the number of concrete bridges constructed each year begins to decrease after the peak years of construction.
4.2. Steel Bridges

A comparison of Figures 28 and 29 indicates that most of the steel bridges in California are older than the concrete bridges. Indeed, between 1929-1948 steel bridges were predominant in California. Also, most of the steel bridges were built between 1949-1968, while most of the concrete bridges were built 1959 and 1973.

Contrary to the construction trends of California bridges, the construction of steel bridges in California has a flatter bell trend, as shown in Figure 29. The peak of construction of steel bridges in California occurs earlier than the peak in the general construction of bridges in California. The peak occurs in 1954-1958, where a total of 397 steel bridges were constructed, which is equivalent to 14.5% of California’s steel bridges.

There is a gradual increase in steel bridge construction from 1908 and earlier to 1934-1938, however the amount of steel bridges constructed begins to decrease until 1944-1948, where the number of steel bridges being built begins to climb again. The decrease in steel bridge construction
does not begin until after the steel construction peak in 1954-1958, and the number of steel bridges constructed does not increase again.

**Figure 29: Age of Steel California Bridges Represented by Percentage of Bridge Count [NBI 2013]**

5. **Functional System**

California bridges have many different functional systems; each system accommodates for different volumes of traffic and mobility. There are four sets of classification for functional systems: principle arterial, minor arterial, collector, and local. Arterials are roadways with high traffic volumes and a high degree of mobility. (U.S. Department of Transportation, Federal Highway Administration) Principle arterial systems include interstate and other freeway and expressway bridges. Minor arterials provide connections to major arterials with lower levels of mobility, but they are not as concentrated as principle arterials. Minor arterials include streets that allow faster speed limits. Collector systems connect local roads to traffic on arterial roads. Locals are roads that do not include arterials or collectors; locals are surface streets.

The distribution of functional systems of California bridges shown in Figure 30, indicates that 42% of bridges are located in principle arterial systems such as interstates, freeways, and
expressways, 16% of bridges are located in minor arterial systems, 19% of bridges are located in collector systems, and 23% of bridges are located in local systems.

![Pie chart showing distribution of bridge systems](image)

*Figure 30: Functional systems of California bridges represented by percentage of bridge count [NBI 2014]*

6. Structural Status

![Image showing cracks in structure](image)  
*Figure 31: The cracks in the structure indicate that this is an example of structurally deficient bridge*

![Image showing traffic congestion](image)  
*Figure 32: Since this bridge does not accommodate traffic flow, this is an example of functionally obsolete bridge*

The National Bridge Inventory categorizes the structural status of bridges into three different classifications: structurally deficient bridges, functionally obsolete bridges, and bridges that have no deficiency. Neither functionally obsolete nor structurally deficient bridges necessarily implies
lack of safety. The federal government uses the first two classifications to identify bridges eligible for rehabilitation or replacement and therefore to allocate federal funds to each state based on needs (Woods 2008). According to the California Department of Transportation, approximately 95% of the bridges are designated as structurally deficient because of minor cracks in the concrete deck “…[and] the remaining 5% of the bridges may or may not warrant repairs depending on the nature of the problem” (Senate Transportation & Housing Committee, 2007). Functional obsolesce is a condition that implies a bridge is “no longer by design functionally adequate for its task,” (ASCE, 2012) for instance, the bridge does not have enough lanes to accommodate traffic flow or the vertical clearance is restrictive or it does not meet safety regulations.

As shown in Figure 33, the United States has 610,749 bridges nearly 145,890 (24% of total bridges) of those bridges are categorized as either structurally deficient or functionally obsolete. Moreover, there is a total of 61,365 (14% of total bridges) structurally deficient bridges and 84,525 (10% of total bridges) functionally obsolete bridges in the United States. The area of structurally deficient and functionally obsolete bridges account for 27% of the total area of bridges in the United States, as shown in Figure 34. Compared to the percentage of total count of structurally deficient bridges, the percentage of total area of structurally deficient bridges is lower, with 7% of
the total bridge area in the United States. Conversely, the percentage of total area of functionally obsolete bridges is larger, with 20% of the total bridge area in the United States.

Figure 33: Structural status of United States Bridges represented by percent of total bridge count [NBI 2014]

Figure 34: Structural status of United States bridges represented by percent of total bridge area [NBI 2014]

California bridges are not exempt from this pattern. As shown in Figure 35, nearly 6,807 bridges (27% of the California bridges) of the bridges in California have a type of deficiency.
Moreover, a total of 2,501 bridges (10% of California bridges) are structurally deficient and 4,306 bridges (17% of California bridges) are functionally obsolete. The percentage of bridge area that is deficient is 34% of the total bridge area for the state, which is much higher than the percentage of count. Similarly, the percentages of area for both functionally obsolete and structurally deficient bridges are higher when compared to the percentage of count. The structurally deficient percentage of bridge area is 1% more than the structurally deficient percentage of count; the functionally obsolete percentage of area is 6% more than the functionally obsolete percentage of count.

![Figure 35: Structural status of California bridges represented by percentage of bridge count [NBI 2014]](image-url)
6.1. Southern California Counties

There are 2,532 bridges in the Southern California counties of Kern, Los Angeles, Orange, Riverside, Ventura, San Bernardino and San Diego that have deficiencies, whether structural deficiency or functional obsolescence. The deficiency in Southern California bridges corresponds to 10.0% of the total number of bridges in California. The percentage of bridges deficient in each county by count is shown in Table 2. Results indicate that the county with the largest percentage of deficient bridges is Los Angeles.
Table 2: Bridge deficiency in Southern California counties by percentage of bridge count

<table>
<thead>
<tr>
<th>County</th>
<th>Percentage of Total Deficiency (%)</th>
<th>Percentage of Structural Deficiency (%)</th>
<th>Percentage of Functional Obsolesce (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Los Angeles</td>
<td>35.2</td>
<td>9.1</td>
<td>26.2</td>
</tr>
<tr>
<td>Orange</td>
<td>27.9</td>
<td>5.6</td>
<td>22.2</td>
</tr>
<tr>
<td>Ventura</td>
<td>24.5</td>
<td>8.9</td>
<td>15.7</td>
</tr>
<tr>
<td>San Bernardino</td>
<td>19.6</td>
<td>12.6</td>
<td>6.9</td>
</tr>
<tr>
<td>Riverside</td>
<td>18.4</td>
<td>7.3</td>
<td>11.0</td>
</tr>
<tr>
<td>Kern</td>
<td>16.4</td>
<td>7.4</td>
<td>9.1</td>
</tr>
<tr>
<td>San Diego</td>
<td>16.4</td>
<td>3.4</td>
<td>13.0</td>
</tr>
</tbody>
</table>

The analysis of deficiency by percentage of bridge area indicates that the amount of bridge area deficient in each of the counties analyzed is much higher, with Los Angeles at 42.9% being the highest, followed by Orange and Ventura with 31.7% and 28.6%, as shown in Table 3.

Table 3: Bridge deficiency in Southern California counties by percentage of bridge area

<table>
<thead>
<tr>
<th>County</th>
<th>Percentage of Total Deficiency (%)</th>
<th>Percentage of Structural Deficiency (%)</th>
<th>Percentage of Functional Obsolesce (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Los Angeles</td>
<td>42.9</td>
<td>12.1</td>
<td>30.7</td>
</tr>
<tr>
<td>Orange</td>
<td>31.7</td>
<td>6.5</td>
<td>25.2</td>
</tr>
<tr>
<td>Ventura</td>
<td>28.6</td>
<td>11.3</td>
<td>17.4</td>
</tr>
<tr>
<td>Riverside</td>
<td>24.6</td>
<td>9.5</td>
<td>15.1</td>
</tr>
<tr>
<td>Kern</td>
<td>20.2</td>
<td>10.2</td>
<td>9.9</td>
</tr>
<tr>
<td>San Diego</td>
<td>18.9</td>
<td>6.2</td>
<td>12.7</td>
</tr>
<tr>
<td>San Bernardino</td>
<td>17.2</td>
<td>9.1</td>
<td>8.1</td>
</tr>
</tbody>
</table>

Even though Los Angeles County has the most deficiency in its bridges compared to the other Southern California counties, the majority of the deficient bridges are functionally obsolete, as shown in Figure 37 and Figure 38 and Tables 2 and 3. The amount of functionally obsolete bridges in Los Angeles County is nearly triple the amount of structurally deficient bridges: 9.1% (322 bridges) of the bridges in Los Angeles County are structurally deficient and 26.2% (930 bridges) of the bridges are functionally obsolete.
The ratio of functionally obsolete to structurally deficient bridges is even higher in San Diego County and Orange County. There are nearly quadruple the amount of functionally obsolete bridges to structurally deficient bridges, 13.0% (54 bridges) of San Diego’s bridges are functionally obsolete and 3.4% (205 bridges) are structurally deficient, while 22.2% (256 bridges) of Orange County’s bridges are functionally obsolete and 5.6% (65 bridges) are structurally deficient.

Different from the other counties, San Bernardino County has more structurally deficient bridges than functionally obsolete, 12.6% (176 bridges) of its bridges are structurally deficient and 6.9% (97 bridges) of its bridges are functionally obsolete.

Figure 37: Structurally deficient and functionally obsolete Southern California Bridges represented by count of bridges [NBI 2014]
Kern, Los Angeles, Orange, Riverside, San Bernardino, San Diego, and Ventura counties have 28% of the structurally deficient bridges and 39% of the functionally obsolete bridges in California, as shown in Figure 39 and Figure 40. Los Angeles County has the highest structurally deficient, as well as, functionally obsolete bridge population in Southern California.
An analysis of the relationship between the material composition of bridges and their deficiency was performed. Because most of the bridges in California are made of concrete with a smaller number made of steel, only bridges of these two materials were accounted for in the analysis. As shown in Figure 41 and Table 4, even though the majority of the bridges that are
structurally deficient are made of concrete, a small percentage of each county’s concrete bridge population is structurally deficient. Conversely, as also shown in Figure 41 and Table 4, the percentage of structurally deficient bridges in each county’s steel population is higher compared to the percentage of structurally deficient bridges in each county’s concrete population, with Los Angeles county steel bridges having the largest percentage of obsolete bridges.

Table 4: Material composition of structurally deficient Southern California bridges represented in percentage of bridge count

<table>
<thead>
<tr>
<th>County</th>
<th>Concrete</th>
<th>Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kern</td>
<td>6.3</td>
<td>8.7</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>13.3</td>
<td>42.6</td>
</tr>
<tr>
<td>Orange</td>
<td>3.1</td>
<td>6.1</td>
</tr>
<tr>
<td>Riverside</td>
<td>8.9</td>
<td>9.3</td>
</tr>
<tr>
<td>San Bernardino</td>
<td>5.8</td>
<td>15.7</td>
</tr>
<tr>
<td>San Diego</td>
<td>2.2</td>
<td>6.6</td>
</tr>
<tr>
<td>Ventura</td>
<td>7.9</td>
<td>25.0</td>
</tr>
</tbody>
</table>

For most of the counties, more than 80% of the structurally deficient bridges are composed of concrete, as shown in Figure 41. However, in the San Bernardino County, the structurally deficient population is 76.2% concrete and 23.7% steel.
Similar to the structurally deficient bridge population, the functionally obsolete bridge population is primarily concrete as shown in Figure 42 and Table 5. The percentage of functionally obsolete bridges in each county’s concrete population is relatively low, with the exception of Los Angeles County’s functionally obsolete bridges. The percentage of functionally obsolete bridges in each county’s steel population has a wide range.

Table 5: Material composition of functionally obsolete Southern California bridges represented in percentage of bridge count

<table>
<thead>
<tr>
<th>County</th>
<th>Concrete</th>
<th>Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kern</td>
<td>5.9</td>
<td>10.1</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>34.7</td>
<td>41.4</td>
</tr>
<tr>
<td>Orange</td>
<td>13.9</td>
<td>20.7</td>
</tr>
<tr>
<td>Riverside</td>
<td>8.7</td>
<td>24.1</td>
</tr>
<tr>
<td>San Bernardino</td>
<td>3.2</td>
<td>11.8</td>
</tr>
<tr>
<td>San Diego</td>
<td>7.5</td>
<td>11.8</td>
</tr>
<tr>
<td>Ventura</td>
<td>11.5</td>
<td>18.8</td>
</tr>
</tbody>
</table>
7. Average Daily Traffic on Bridges

According to the California Department of Transportation, the average daily traffic (ADT) on bridges measures the total volume for the year divided by 365 days. The total volume of traffic on bridges is measured with two different classifications, urban and rural, which indicates the type of area the bridges are located. Urban bridges are located in areas where the population is more than 50,000.

The average daily traffic on bridges in the United States is widely distributed throughout the 50 states, as shown in Figure 43. Most of the average daily traffic in the United States does not exceed an average of 200,000,000 vehicles. However, Texas and California are outliers. Texas accounts for 11% of the total average daily traffic in the United States and California accounts for 14.8% of the total average daily traffic. Texas and California both have very large average daily traffic values in urban and rural areas, as shown in Figure 44. California accounts for 17.1% of the total urban traffic and 6.9% of the total rural traffic in the United States. Texas accounts for 12.5% of the total urban traffic and 9.5% of the total rural traffic in the United States.
Figure 43: Total average daily traffic on United States bridges represented by count [NBI 2014]
Figure 44: Average daily traffic on United States bridges represented by count [NBI 2014]
Within California, freeways and interstate bridges are considered to be on principle arterials because of the high volumes of traffic that go through these areas. As shown in Figure 46, 10,716 bridges (42% of the bridges in California) are considered to be on principle arterials. Among the major freeways and interstates in the United States, five major freeways and interstates which
travel through Southern California include Interstate-210 (I-210), Interstate-10 (I-10), US 101, Interstate-5 (I-5), and Interstate-405 (I-405). Freeways and interstates are all considered highways.

Figure 46: Major interstate and freeway bridges in California [NBI 2014]

Figure 47 displays the amount of bridges on these major highways. The I-5 has a total of 1,699 bridges in California, which is equivalent to 15.9% of the interstate and freeway bridges in California. The US 101 has 1,361 highway bridges, which is equivalent to 12.7% of the interstate and freeway bridges in California. The I-10 has 733 bridges, which is equivalent to 6.8% of the interstate and freeway bridges in California. The I-210 has 429 bridges, which is equivalent to 4.0% of the interstate and freeway bridge population in California. The I-405 has 414 bridges, which corresponds to 3.9% of the freeway and interstate bridge population in California.
The most deficiency on the major interstate and highways in California occur on the US 101, as shown in Figure 48. There are 254 bridges that are either functionally obsolete or structurally deficient on the US 101, which is equivalent to 18.7% of the bridges of the total bridges on the US 101. With the same number of deficient bridges, 14.9% of the bridges on the I-5 are either structurally deficient or functionally obsolete. Of the bridges on the I-405, 77 bridges or 18.6% of the bridges on the I-405 are deficient. On the I-10, 85 bridges or 11.6% of its bridges are deficient. The least amount of deficient bridges are on I-210, where only 16 bridges or 3.7% of the bridges on the I-210 are deficient.

For all the bridges on the interstates and freeways, there were more functionally obsolete bridges than structurally deficient bridges. The US 101 and I-10 had almost double the number of functionally obsolete bridges than structurally deficient. The I-405 had 4.5 times the number of functionally obsolete bridges and the I-210 had 15 times the number of functionally obsolete bridges. The I-5 had 1.4 times the number of functionally obsolete bridges.

Figure 47: Major interstate and freeway bridges in California represented by count of bridges [National Bridges-NBI 2012]
The majority of the bridges on the major interstates and freeways are composed of concrete, as shown in Figure 49. As a matter of fact, more than 90% of the bridges in each major freeway and interstate are composed of concrete. The I-210’s bridges are 99.5% (427 bridges) concrete, the I-10’s bridges are 95.5% (700 bridges) concrete, the US 101’s bridges are 90.9% (1,237 bridges) concrete, the I-5’s bridges are 93.0% (1,580 bridges) concrete, and the I-405’s bridges are 97.3% (403 bridges) concrete. The amount of steel bridges are less than 10% of the bridge population on each freeway and interstate. The I-210’s bridges are 0.5% (2 bridges) steel, the I-10’s bridges are 4.7% (33 bridges) steel, the US 101’s bridges are 9.8% (121 bridges) steel, the I-5’s bridges are 7.5% (118 bridges) steel, and the I-405’s bridges are 2.7% (11 bridges) steel.
When analyzing the material composition of the bridges that are structurally deficient and functionally obsolete, the number of concrete structurally deficient and functionally obsolete bridges are dominant in most of the major California interstate and freeways, as show in Figure 50. However, on the US 101, the number of steel structurally deficient bridges, 68 bridges, is more than the number of concrete structurally deficient bridges, 19 bridges. The US 101 has the most structurally deficient steel and functionally obsolete steel and concrete bridges out of all of the major freeways and interstates. The I-5 has the most structurally deficient concrete bridges within the major highways in California.
Figure 50: Material composition of structurally deficient and functionally obsolete interstate and freeway bridges in California represented by count of bridges [National Bridges-NBI 2012]

8.1. Southern California Counties

Major interstates and freeways have presence in Southern California Counties, however, for most of the counties, with the exception of Los Angeles counties, at most, a couple freeways and interstates travel through the counties. In Kern, the only major freeway that travels through the county is the I-5. In Orange County, the only major freeways that travel through the county are the I-5 and I-405. In Riverside County, the only freeway that travels through the county is I-10. In San Bernardino County, the only major highways that travel through the county are the I-210 and the I-10. In San Diego County, the only major freeway that travels through the county is the I-5. In the Ventura County, the only major freeway that travels through the county is the US 101. Contrary to these counties, all of the major freeways travel through the Los Angeles County.

As shown in Figure 51, the most interstate and freeway bridges are located in the Los Angeles County, which indicates the most traffic is directed towards this area, presumably the city of Los Angeles. High populations of bridges are also present in Orange County and San Diego County.
9. Ownership

The ownership of bridges in California are classified under 15 different categories within the National Bridge Inventory (NBI). However, the majority of these classifications account for small numbers of bridges that are not able to be used for analysis. So, these classifications are displayed under “Other,” which represents bridges in California that are owned by town, state park, local park, other state or local agencies, private railroad, local toll, and federal. Other classifications include state, county, and city. The ownership of the bridges determines where the responsibility of repairing and maintaining bridges lies. State bridges are managed by the California Department of Transportation (CalTrans). County and city bridges are managed by the respective areas the bridges are located.

As shown in Figures 52 and 53, the ownership of the most of the bridges in California and the majority of the California bridge area is by the state. The state owns 12,347 bridges (49% of the California’s bridge population). However, the percentage of count does not correspond for the percentage of bridge area for California, 77% of California’s bridge area is managed by the state.
Counties and cities in California also own a considerable amount of bridges. Counties own 7,253 bridges (29% of the California’s bridge population) and cities own 4,711 bridges (18% of California’s bridge population). Bridges managed by “other” are 1,095 bridges (4% of California’s bridge population, with the number of federally owned bridges being the greatest. However, similar to the state ownership, the percentage of bridge count does not correspond with the percentage of bridge area. The percentage of area that counties, states, and “other” own is much smaller than the percentage of count of bridges for California bridges.

![Figure 52: Ownership of California bridges represented by percentage of bridge count [NBI 2014]](image1)

![Figure 53: Ownership of California bridges represented by percentage of bridge area [NBI 2014]](image2)
10. Federally and Non-Federally Aided Bridges

Within the National Bridge Inventory (NBI), the bridges in the United States are identified as federally-aided bridges or non-federally aid bridges. There are more federally aided bridges than non-federally aided bridges. There are 320,215 federally-aided bridges and 284,872 non-federally aided bridges.

As shown in Figure 54, of the fifty states and Puerto Rico thirty six states have more federally funded bridges than non-federally funded bridges, of which include Texas and California. The states that receive the most federal aid are Texas and California. In Texas, 33,866 bridges are federally funded, which is equivalent to 10.6% of the total federally aided bridges. In California, 17,679 bridges are federally funded, which is equivalent to 5.5 percent of the total bridges that are federally aided. Washington D.C. and Delaware have the least amount of federal aid. Washington DC has 201 federally funded bridges, which is 0.1% of the total federally funded bridges, and Delaware has 573 federally aided bridges, which is 0.2% of the total federally funded bridges.

The states that have the most bridges that receive no federal aid are Texas and Iowa. Texas has a total of 18,008 bridges that receive no aid, which is equivalent to 40.0% of the bridges in the United States that receive no federal aid. Iowa has 16,704 bridges that receive no federal aid which is equivalent to 37% of the bridges in the United States that receive no federal aid. The states with the least amount of bridges that have no federal aid are Washington DC and Rhode Island. Washington DC has 44 bridges that have no federal aid, which is equivalent to 0.1% of bridges in the United States that receive no federal aid. Rhode Island has 128 bridges that receive no federal aid, which is equivalent to 0.3% of the total number of bridges in the United States that receive no federal aid.
Figure 54: Federally and Non-Federally Funded United States bridges represented by count of bridges [NBI 2014]
The cost of federally aid highways and non-federally aid highways have been increasing since the 1990s, as shown in Figure 55. Non-federally aided highway bridges cost more per square feet for the majority of the time the NBI recorded the cost of bridges. The trend for the cost of non-federally aided bridges began to drop in 2009 after the cost peaked at $253/ft$^2$. The cost for federally aided highways peaked much earlier than non-federally aided highways. The cost for federally aided highways peaked in 2007 at $205/ft^2$.

Figure 55: Cost of California bridges represented in cost per unit of area [NBI 2012]

### 11. Conclusion

This study is aimed at understanding and investigating the National Bridge Inventory (NBI) database and retrieving, organizing and analyzing information provided for the state of California. The information, patterns and trends presented in this report is considered essential to users, owners, maintenance and inspection agencies as well as designers. The findings in this research provide information on bridge geographic distribution and bridge attributes as well as on the conditions of the bridges in California in terms of count and deck area. Significant findings about the 25,406 bridges that California has are made in regards to material composition, wearing surface and deck protection, age, functional system, structural status, average daily traffic, ownership, as well as, federal aid and non-federal aid bridge distribution. An emphasis is made on the analysis
of bridges in the Los Angeles County and the surrounding Orange, Ventura, San Bernardino, Riverside, Kern and San Diego counties in Southern California, which together account for 39% of the total bridge population in California.

This study proves the great potential of the NBI database for extracting essential information on bridges in the United States. Moreover, it indicates that combining the data base with a search engine, such as that of National Bridges, can help to retrieve additional information that the one found in the NBI website. Once the information is retrieved and analyzed using data visualization techniques, additional trends and relationships could be found and then revealed about bridges in the United Stated. These findings would otherwise remain hidden in the NBI database, the largest bridge data collection in the world.

Based upon the results of this research, the following conclusions were reached in regards to bridges in the State of California:

1. The state of California has the fourth largest bridge population (4.2%) in the nation, with Texas having the largest (9.0%). The Los Angeles County alone has 14% of the bridge population in California. Counties surrounding Los Angeles County: Orange, Ventura, San Bernardino, Kern, Riverside and San Diego, together account for 25% of the bridges in California.

2. In addition to the population of bridges, the bridge deck area is an important parameter to be accounted for because it not only gives information on how much deck area these bridges occupy but also it could be used as a measure of costs of rehabilitation or replacement of bridges.

3. On a bridge deck area basis, the state of California has the second largest bridge area (7.9%) in the nation, with Texas having the largest (12.5%)

4. In the United States concrete is the predominant structural material for bridges. The population of concrete bridges in the nation is 66% followed by steel with 30%. After Texas, California is the state with the largest count (3.5%) and area (6.7%) of concrete bridges in the nation. Furthermore, 85% of the total area of bridges in California corresponds to concrete bridges while only does for 14% steel. In a few states, such as Maine, New York, Michigan, New Jersey, and Maryland, the predominate structural
material for bridges is steel. This seems to indicate that there may be a geographic criteria when choosing structural materials for bridges.

5. In the United States, 88% of the bridges have a form of wearing while 32% have deck protection. In California, 58% of the bridge population in the state has wearing surface while only 2% of that has deck protection. Texas is the state that has the largest percentage of bridges with wearing surface and deck protection (10% and 23% of the total US bridge population with wearing surface and deck protection, respectively), Ohio with 6% and 5% respectively, Iowa with 4 and 1.5%, respectively, South Caroline 2% and 5% and California with 3% and 0.2%, respectively. It is inferred that bridge geographical location may not play a role in the criteria to use wearing surface and deck protection.

6. When bridge wearing surfaces are used, 66% of the total wearing surface area in the state of California is a form of concrete wearing surface, while only 4% is bituminous wearing surface; 30% is epoxy overlay.

7. When deck protection is used, the predominant type is polymer impregnated deck protection covers, which is used in 46% of the total area of bridges with deck protection; epoxy coated reinforcing only covers 26% of the total area of bridges with deck protection.

8. Between the years of 1959 and 1973 about 28% of the total area of bridges in the United States were built, which indicates that 28% of the bridges area are past or approaching the 50-year life span.

9. The predominant structural material for bridges in California up to 1958 was steel. After that year, the population of concrete bridges with respect to steel bridges has been increasing. The reason for this may be that about that time pre-stressed concrete started to be the structural material of choice for a wide range of bridge spans.

10. Between the years of 1959 and 1973 about 41.0% of the total count of concrete bridges in California were built, which indicates that those concrete bridges are past or approaching the 50-year life span. Between the years of 1954 and 1968 about 38.7% of the total count of steel bridges in California were built, which indicates that those steel bridges are well past or almost at the 50-year life span.

11. Principle arterial functional systems account for the highest percentages (42%) of bridges in highway systems in California, followed by local functional systems (23%), with minor arterials and collectors sharing relatively smaller portions. The reason for this distribution
may be that a large population of new bridges is on principle arterials. This distribution of functional classification reflects decisions made by cities, counties, or the California Department of Transportation California or Metropolitan Planning Organizations as part of a transportation planning in the state.

12. In the United States, about 27% of the total area of bridges is categorized as deficient (or 20% functionally obsolete and 7% structurally deficient). In California, about 42.9% of the total area of bridges in the state is categorized as deficient (or 30.7% functionally obsolete and 12.1% structurally deficient). In Southern California, the Los Angeles County has the highest percentage of count of deficient bridges when compared with its surrounding counties (Kern, Riverside, Riverside, Ventura, Orange, San Bernardino, and San Diego), with 35.2% deficient bridges (about 26.2% functionally obsolete; 9.1% structurally deficient). These statistics and trends could be the basis for competing and allocating federal funding.

13. Functionally obsolete bridges are predominant in the United States, California, and in the Southern California counties studied in this research, with the exception of the San Bernardino county where structurally deficient bridges are predominant.

14. California accounts for the largest average daily traffic (ADT) in the United States with 15% of the total ADT in the country followed by Texas with 11%. The ADT in California is largely predominant in urban traffic when compared to local traffic. These statistics, besides serving as an indicator of the daily amount of traffic that the state has, could be one of the basis for decisions regarding transportation planning or air pollution associated with transportation and for federal funding for the maintenance and improvement of highways.

15. When major highways in the Southern California area were compared, I-5 is the highway with the largest bridge population (15% of the bridges in California), followed by US 101 with 12% of the state bridge population. US 101 and I-405 are the highways with the largest number of deficient bridges (19% of the bridges on each are categorized as deficient) followed by I-5 with 15%. Except for US 101, the population of structurally deficient concrete bridges was larger than that of structurally deficient steel bridges for major freeways in Southern California.

16. The state of California has the ownership and maintenance responsibilities of most of the bridges in the state or 77% of the bridges in the state. This distribution of ownership
reflects that the state is not only responsible for maintaining more than three quarters of the bridges in the state, but also has an essential in the state transportation planning.

17. California has 6% of the total federal aid bridges in the United States, the second largest in the nation after Texas with 11%. The unit cost of federal aid bridges has been lower than that for non-federal aid bridges since 2002, except in 2011 (last NBI data) when the unit cost for non-federal aid bridges dropped in 18% with respect to the federal-aid bridges.

11.1. Recommendations for future NBI Research

Although this study addressed many questions concerning the NBI data for bridges in the State of California, several other questions were raised during the course of the research that deserve further investigation. The following topics are areas where additional research into the NBI data is needed:

1. A search engine is needed as a tool to extract large sets of data and greater utilize the database.
2. Create a data base that is based on time by combining the current NBI edition with its previous editions.
3. Investigate how different bridge attributes change over time. This can be achieved with the time-based database described above. It particularly important to monitor trends in bridge performance in terms of strength and serviceability over time.
4. Create an excel engine to program the information found in the ASCII file, to greater utilize the NBI
5. Analyzing the effects of external and environmental factors on bridge strength and serviceability.
12. Works Cited

12.1. Images

Figure 3: http://www.myonlinemaps.com/images/california-county-map.gif

Figure 5: https://upload.wikimedia.org/wikipedia/commons/8/86/VTbridge2009.jpg

Figure 6:
https://upload.wikimedia.org/wikipedia/commons/b/b0/Pasadena_Colorado_Street_Bridge_2005.jpg

Figure 31: http://images.sodahead.com/polls/001277241/crumbling_bridge_300x225_xlarge.jpeg

Figure 32: https://www.transportation.gov/sites/dot.gov/files/pictures/Obsolete_bridge.jpg

Figure 45: Major freeways in California
Figure 45:

12.2. References

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