STRUCTURAL IMPORTANCE CLASSIFICATION OF RAILROAD STRUCTURES FOR SEISMIC DESIGN

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Need for Seismic Design

Seismic design is needed because key routes have become more sensitive to service disruptions and government agencies are more insistent on seismically safe structures. Economic pressures have caused railroads to consolidate traffic on a few key routes. Communities are demanding the relocation and consolidation of rail lines into corridors in urban areas. This funneling of traffic onto key mainlines and elimination of detour routes has made the continued operation of the key mainlines critical to the financial success of the railroad industry.

An example of this funneling of traffic is the Alemeda corridor. The three routes between the ports of Los Angeles and Long Beach and the Union Pacific and BNSF mainline are being consolidated into one central corridor. This corridor will handle all of the rail traffic to the ports of Los Angeles and Long Beach. These ports handle a large amount of the container traffic from Asia. If this corridor is ever damaged, the service disruption will affect most of the railroads in the United States.

Various government agencies in California have attempted to force their seismic retrofit solutions on the western railroads. The intent of the seismic retrofits was to prevent damage to highways or other facilities underneath the bridge. The proposed retrofits would make the bridge less safe for railroad operation. The proposed solutions include:

- Adding cable restraints between the spans that would prevent the spans from falling off of the piers during an earthquake. The connection of the cable restraints to the superstructure can create fatigue sensitive details and localized damage to the ends of the spans. The damage to the end of the span can result in loss of support under the bearings. Ironically, most designers ignore the contribution of the rails that may provide a more effective and less damaging restraint than cables.

- Adding concrete blocks in front of the bearings to prevent the span from being shaken off of its bearings. The concrete blocks would prevent bridge inspectors from inspecting the bearings. If the bearings cannot be inspected, unsafe conditions can develop undetected.

- Adding brackets to a span so that it would strut the backwalls apart if they started to overturn during an earthquake. The span might collapse if it had the compression forces from the backwall and the bending forces from train load.

Past experience dealing with government bodies should show us, if we do not solve our problems ourselves, a solution will be forced on us and it may not be the one we want.

What is Seismic Design?

Earthquakes are infrequent randomly occurring ground motion of various degrees of magnitude. This makes the determining an exact seismic design load impossible. Fortunately, the frequency of earthquakes in a geographic area is statistically definable. Also, there is an
inverse relationship between the frequency of seismic events and the magnitude of the event. Through statistics, the maximum probable seismic event can be predicted for a given period of time. Using the maximum probable seismic event, design loads can be determined.

Unfortunately, if a long return period is used, the design loads for the maximum probable seismic event are so high that it would be economically unfeasible to design a structure to respond elastically for the event. Also, due to the infrequency of seismic events, the structure may not experience the maximum probable event during its lifetime. As with most engineering problems, the engineer is faced with balancing the need for safety while controlling costs.

Designing structures to respond differently to different magnitudes of earthquakes reduces costs. A structure designed for seismic events would be designed to remain serviceable after a relatively frequent seismic event. The same structure would be designed to sustain a limited amount of damage for a less frequent greater magnitude event. After a very infrequent large magnitude event, a perfectly seismic designed structure would not collapse but would sustain so much damage that it would have to be replaced.

Most civil engineers are familiar with a design problem that is similar to seismic design. The similar design problem is the sizing of drainage structures. Both design problems attempt to create a structure that is appropriate for a randomly occurring, yet statistically definable, event. In both processes, the magnitude of the design event increases in relationship to decreases in frequency. A ten-year storm produces less water than a hundred-year storm. A hundred-year return period earthquake has less damaging ground motion than a thousand-year earthquake. In both design processes, different levels of performance are expected for different event frequencies. A generally accepted procedure for sizing a culvert is for the pipe to run full with a ten-year storm event and to have one diameter of head for a hundred-year storm event. As outlined above, different levels of performance are expected for different seismic events.

In some cases, drainage structures cannot be designed to the generally accepted performance levels due to other circumstances. In some cases, larger drainage openings are provided to prevent water from backing up on adjacent property owners or over topping the fill. In other cases, smaller openings are used because providing the optimal opening is expensive and the fill is tall and strong enough to handle the additional water. Normally, parties affected by drainage structures are easily defined in contrast to the parties that are affected by the seismic design of a structure. The process of looking at the parties that will be affected by a drainage structure is left to engineering judgement. In seismic design, the parties that will be affected by the performance of the structure during a seismic event may not be clear without a formal review process. Structural Importance Classification is the process of reviewing the needs of the parties that will be affected by the performance of the structure during a seismic event and creating design parameters to meet their needs.
Performance Criteria

The first step used to develop the Structural Importance Classification system was the development of performance criteria. The American Railway Engineering and Maintenance of Way Association adopted three levels of seismic performance. The seismic performance levels are based on the design stress levels of the members in the structure;

- All of the members respond elastically to the occasional seismic event
- Critical non-redundant members respond elastically, with the balance of the structure deforming plastically to the rare seismic event
- Full plastic deformation during the very rare seismic event

These performance criteria or limit states are; serviceability, ultimate and survivability. Figure 1 shows the characteristics of the limit states.

![Figure 1](Ground Motion and Performance Criteria Limit States)

<table>
<thead>
<tr>
<th>Performance Criteria Limit State</th>
<th>Frequency</th>
<th>Average Return Period</th>
<th>Design Stress Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serviceability</td>
<td>Occasional</td>
<td>50 – 100 years</td>
<td>Elastic</td>
</tr>
<tr>
<td>Ultimate</td>
<td>Rare</td>
<td>200-500 years</td>
<td>Elastic / Plastic</td>
</tr>
<tr>
<td>Survivability</td>
<td>Very Rare</td>
<td>1,000 – 2,400 years</td>
<td>Conceptual Design</td>
</tr>
</tbody>
</table>

A properly designed structure will sustain a moderate amount of damage during an occasional seismic event (serviceability limit state). Temporary speed restrictions may be necessary to compensate for minor damage to the structure, track out of alignment and other moderate damage. The structure will perform elastically during the seismic event.

During a rare seismic event (ultimate limit state), the structure may sustain heavy damage that can be repaired economically. Track and structures may be out of service for a short period of time. Non-redundant primary structural members will be expected to perform elastically. All other structural members may perform plastically during the seismic event.

Very rare earthquakes (survivability limit state) are massive devastating earthquakes. Severe damage will occur during a seismic event of this type. The structure will be expected not to collapse but may be severely damaged during one of these events. The structure may require replacement or major rehabilitation before resuming operation. The forces that will occur during this type of event are impossible to determine. Past seismic events have shown that geometry, distribution of mass, ductility and structural details have more effect on the performance of the structure than strength. Therefore, the A.R.E.M.A. recommendations for seismic design require that structures be designed using design characteristics that have proven to be seismically resistant in the past.
Structural Importance Classification

The Structure Importance Classification examines the proposed structure and its environment to determine the return period for the design seismic events. The A.R.E.M.A. recommendations for Structural Importance Classification are divided into three criteria; immediate safety, immediate value and replacement value. The three criteria are defined later in this paper. The specifications give the engineer a method of assigning a value of 1 to 4 for each of the criteria. The higher the value assigned to the criteria, the greater required performance or cost. All of the factors are used to determine the return period for each of the performance levels. Weighting factors are used to convert the Structural Importance Classification values into the return periods for the performance criteria limit states. The weighting factors are designed so that the immediate safety criteria have the greatest effect on the return period for the serviceability design seismic event. The return period of the ultimate design seismic event is mainly affected by the immediate value criteria. The replacement value criteria has the greatest effect on the survivability design seismic event.

Immediate Safety

The immediate safety criteria identify the performance required during an occasional seismic event. Immediate safety identifies parties that would be affected by damage to the bridge during and immediately after a seismic event. The three area of concern for immediate safety are occupancy, hazardous material and community lifelines. Occupancy attempts to identify the risk to passengers and crew during a seismic event. The value for occupancy is lower on freight only lines than lines that carry a significant amount of passengers. If the structure is over a busy highway, the occupancy of the highway should also be considered. Hazardous material identifies the risk to the community and environment due to the possible release of hazardous material during or immediately after a seismic event. The factor is based on the amount of hazardous material traffic expected to travel over the bridge. A community lifeline is service that will be required by the community after an earthquake. Roads that ambulances use to reach a regional medical center are community lifelines. Telephone, electric and water lines are considered community lifelines. Even waterways used by fireboats are considered community lifelines. If failure of the bridge would hamper the rescue of earthquake victims, it becomes a community lifeline issue. The three immediate safety factors are combined using the method described in the A.R.E.M.A. manual to establish the value for immediate safety.

Immediate Value

The immediate value criteria identify the cost to the railroad of having the structure out of service. The two considerations used to determine the immediate value are utilization and the availability of a detour route. The utilization factor is determined by the number of million gross ton miles that will be carried by the bridge each year. This factor may be adjusted due to the revenue produced by the traffic that the structure will carry. The factor should be adjusted upwards if the traffic carried by the structures produces high revenues but is relatively light. The other factor to be examined is the availability of detour routes that can be utilized soon after a seismic event. Adjacent bridges are unsuitable for detour routes because they will experience the same ground motion as the bridge in question. A detour route that would create operational problems is also a poor detour route. Other factors should be considered when determining the immediate value of the structure. Does the use of the structure by others generated revenue for
the railroad? Fiber optics lines on the bridge are an example of others using the bridge to generate revenues. Also, other disruptions to railroad operations should be considered. The gross tonnage carried by a bridge that is used by empty unit coal trains returning to the mines may be small, but the loss of the structure would disrupt unit train operations. The specifications define how these factors are combined to determine the value of the immediate value factor.

**Replacement Value**

The replacement value criteria quantifies the cost of replacing the structure in terms of dollars and time. Three factors are used to determine the replacement value of the structure; span length, bridge length and bridge height. Span length recognizes that longer spans are more expensive and time consuming to obtain and set. Bridge length and height recognizes the time and cost of replacing long and high structures. Other factors that increase the difficulty of replacing the structure should be examined when determining replacement value. These factors include multiple tracks, moveable structures, difficult foundations, urban locations and difficult access.

**Combining Factors to Determine Return Period**

The structural importance factors are combined using the weighting factors as described in the A.R.E.M.A. manual. A range of average return periods (see Table 1) is associated with each performance criteria. The average return period is calculated by using a linear relationship between shortest and longest average return period associated with performance criteria. A structural importance factor of one is associated with the shortest period. A structural importance factor of four is associated with the longest period.

**Determining Base Acceleration**

The A.R.E.M.A. manual contains base acceleration maps for return periods of 100, 475 and 2,400 years. In most cases, the return period defined by the Structural Importance Classification will not correspond to these values. For return periods between the standard periods, the value of the base acceleration can be interpolated between the base accelerations for the standard periods. For a return period less than 100 years, the base acceleration in rock for 100 years should be used if additional information is not available to determine the base acceleration.

**Designing the Structure**

The guidelines provide methods for designing the structure using either a modal analysis or an equivalent lateral force procedure. The bridge’s configuration defines which procedure can be used. The guideline also defines the load combination for design.

**Summary**

The seismic design guidelines have been written to provide seismically safe railroad structures while accounting for the uniqueness of the railroad environment. Seismic design has not been a priority for railroads in the past because railroad structures have performed well during seismic events. It has been argued that the acceptable performance of railroad structures during past seismic events insures that the structures will perform well in the future. The problem with this argument is that the design factors that made the structures resistant to earthquakes were not codified. Changes in material and design philosophy can eliminate the design factors that make a structure seismically resistant. The widespread use of concrete spans
has changed the relationship between mass of the span and the ability of the foundation to resist the movement of the mass during an earthquake. The creation of the A.R.E.M.A. seismic guidelines will allow seismically resistant structures to be designed that will be unaffected by changes in materials or design philosophy without a dramatic increase in cost.