

**COMPARISON OF RAILCAR AND BRIDGE DESIGN LOADINGS FOR  
DEVELOPMENT OF A RAILROAD BRIDGE FATIGUE LOADING**

by

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## **ABSTRACT**

AREMA fatigue design criteria for girder bridges do not have a specified loading other than a comparison of the effects of unit-train coal railcars representing a heavily loaded train. The use of the coal train is realistic in its effects but testing has shown that its effectiveness is limited in predicting maximum fatigue damage to a narrow range of span lengths. The Cooper E Loading also has limited use since the loading is largely governed by the uniform load pattern precluding any cycling of bending moment as is reflected by actual railcar loadings. In addition, the current criteria focus on mid-span effects while fatigue analysis needs to consider all locations on girder spans.

AREMA has also adopted the Alternate Live Load which addresses heavy axle loadings on shorter spans. The Alternate Live Load can be useful in fatigue analysis along with the unit-train coal car. The Association of American Railroads also specifies minimum railcar dimensions for design of railcars. While intended for railcar design, the loading dimensions are useful for comparison to the unit-train coal railcar and the Alternate Live Load.

This paper will examine the advantages and disadvantages of the available loadings to determine their effectiveness for fatigue analysis and design in addition to providing a proposal for fatigue loadings for future design and analysis of girder bridges.

## **INTRODUCTION**

Fatigue analysis, whether for design or rating of steel railway girders, needs to account for the possibility of a high number of fatigue cycles. Railroad loadings are different from highway loadings in their interaction between the bridge span and the axle loadings. For

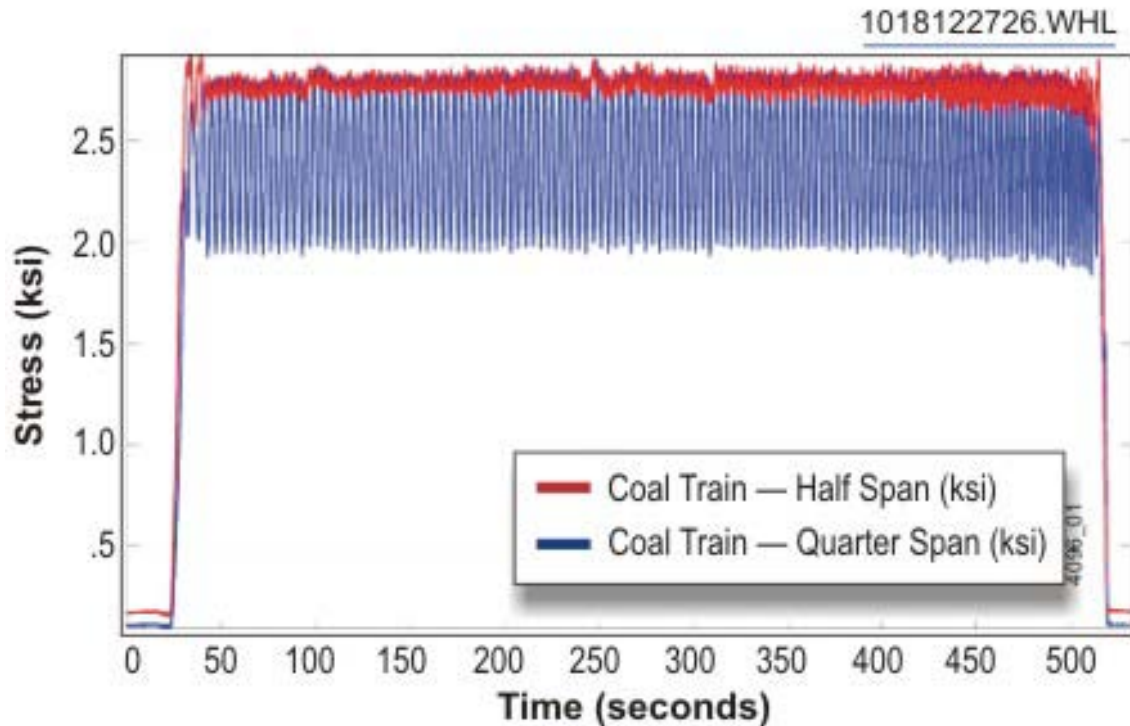
highway loadings, each heavy truck vehicle that crosses a bridge will generate one or two cycles depending upon the length of the span. For this type of loading, the maximum moment of the loads on the bridge will create the magnitude of the fatigue cycle. For railroad loadings, the generation of variation of bending moments can be a more complex process. The process is further complicated by the wide variability in railcar types and length dimensions used by the industry.

The complication of fatigue analysis for railway loadings is shown in Figure 1. This behavior has been reported in both theoretical terms (1), and as a result of testing of a railroad bridge in service (2). The trains investigated were “unit trains” where all cars were of identical length dimensions and the car weights are identical with the load evenly distributed across all axles and wheels.

Figure 1 displays common behaviors for railway loadings that are not experienced in any great amount for highway loadings. The first item of note is that the overall magnitude of live-load stress at the quarter-points and mid-span is essentially equal. The location of absolute maximum live-load moment for railway loadings is variable depending upon span length and the positioning of the axles on the span. Depending upon the location of the absolute maximum moment, the live-load moment at the quarter-points can be quite high in relation to mid-span live-load moment. This is especially critical for spans with partial-length cover plates.

For fatigue analysis, Figure 1 represents even more important information. The figure displays that at the quarter-points that the live-load moment is much more variable between its maximum and minimum than what is experienced at mid-span. This variation is called the moment range or the difference between the maximum and minimum live-

load moment. In addition to the overall maximum moment creating a potentially large fatigue cycle, the moment range can be contributing to fatigue accumulation.



**FIGURE 1: Girder Stresses Under Unit Coal Train With 53-foot Railcars (2)**

The critical feature of the moment range is the potential to create significant cycles with a much higher cycle count for the moment range versus the maximum moment. It is apparent from an examination of Figure 1 that both maximum moment and moment range from any car type may have an overall high magnitude anywhere along a span that must be accounted for in design and rating for fatigue and overall load capacity.

Currently no reference loading exists for design or rating of fatigue details in Chapter 15 of the AREMA Manual of Railway Engineering (3). Analysis behind the current AREMA fatigue provisions were based on the unit coal train. This train type is quite common on most railroads, but other car types may have more severe

characteristics on certain span lengths than the unit coal train. This study is examining a variety of railcar types to see what characteristics are necessary for a reference loading that can serve the purpose of both design and rating. The loading needs to provide a bending moment value combined with a certain number of cycles that, in effect, provides a reference fatigue train for comparison with actual train types.

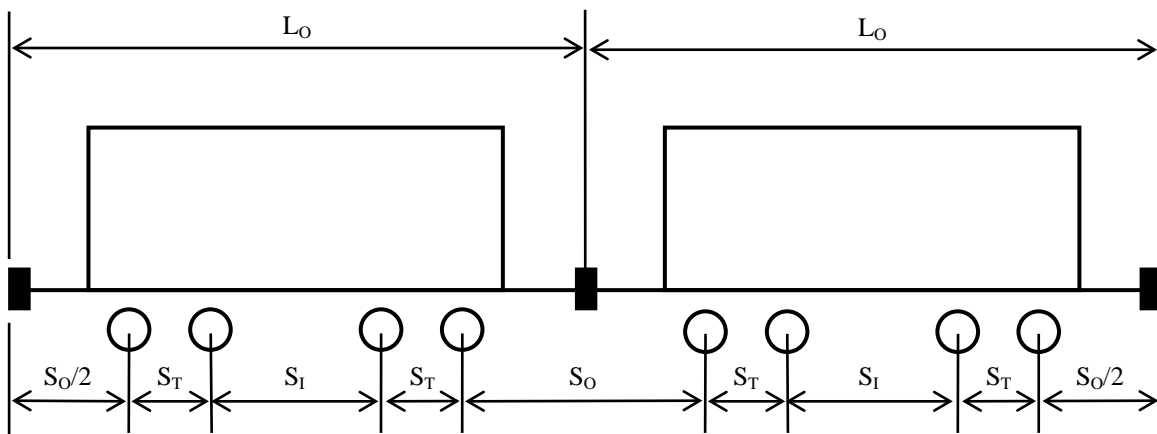
For design, it is desirable to have a reference loading that will create a more conservative bending moment value than the current actual loadings for safety in fatigue design of connections and details. The reference loading should also be a basis for a sufficient cycle count so that the overall train count developed from the stress ranges due to the bending moment will be sufficient for the estimated life of the bridge. For rating, it is desirable to have a reference loading that provides a reasonable idea of fatigue life of any structure based on a number of trains and that the reference loading can be easily translated or converted into any other kind of train composed of actual railcar types for a comparison to the reference loading. What this means for either design or rating is the development of a fatigue train with a given number of railcars, with these railcars having dimensions that are reflective of actual equipment and with axle loadings consistent with those in use (either actual or design) at the present time and for the future.

The Cooper E80 Loading (4) is useful for the overall design of a bridge in terms of maximum moment for girder design. It does not provide dimensions reflective of current equipment nor does it provide any meaningful basis for a number of cycles per train crossing to develop any comparison. By these terms, a new loading is needed providing a realistic train can be used specifically for this purpose.

## CURRENT LOADINGS

### Actual Loadings

Table 1 provides a listing of the equipment used in this study. The dimensions provided in the table, except for the locomotive, represent current loadings which have an allowable gross weight of 286,000 pounds on four axles for cars longer than 42 feet. This gross weight equates to an axle loading of 71,500 pounds. Figure 2 displays the dimensions used in this analysis which are a rearrangement of the typical published dimensions.



- $L_O$  - Overall length of railcar measured over the pulling face of the coupler
- $S_I$  - Inboard Axle Spacing, the distance between the inside axles of the railcar
- $S_O$  - Outboard Axle Spacing, the distance between the outside axles of the railcar
- $S_T$  - Truck Axle Spacing, the distance between the adjacent axles of a truck.
- $n$  - number of axles per railcar
- $P$  - axle load
- GW - Gross Weight ( $nP$ )

**FIGURE 2. Typical Dimensions For Railcars Used In This Study**

**TABLE 1. Dimensions For Locomotive and Railcars In This Study.**

Type	L <sub>O</sub>	S <sub>O</sub>	S <sub>I</sub>	S <sub>T</sub>	GW
Six Axles Locomotive	74.00	11.89	34.79	6.83	429,000
Four Axles Sand/Cement Hopper	41.96	6.71	23.58	5.83	286,000
Coal	53.08	6.75	34.67	5.83	286,000
Long Hopper	69.00	6.71	50.63	5.83	286,000
TOFC	94.67	22.83	60.17	5.83	286,000

The locomotive listed in the table is the typical six-axle locomotive. Modern freight locomotives are six-axle versions with four-axle locomotives built for passenger or yard service only at this time. For this study, an axle loading of 71,500 pounds is assumed for all six axles of the locomotive, for an overall weight of 429,000 pounds. This weight is only slightly high for actual examples as 432,000-pound locomotives have been constructed through the years and this weight is prevalent in locomotive construction currently (5). Four-axle locomotives are still in use on freight railroads, but the loads and axle spacings are such that some current freight equipment generates higher bending moments than those locomotives.

In the table, the minimum length for the four-axle railcar is represented by the sand/cement hopper car that is commonly used. The coal car represents the majority of unit-train loadings in use today. While not the most densely loaded cars, the configuration represents the most common type of unit train on most Class 1 railroads and for certain span lengths are most likely currently providing the most fatigue damage.

The long hopper is used in the plastics industry. The length of this car is close to the maximum constructed length for open or covered hoppers. The extremes of their lengths are represented by the sand/cement hoppers and the long hopper. The lengths of these cars are closely associated with the variety of lengths of cars in the tank car fleets currently operating on North American railroads. The variation in length between extremes in hopper lengths also accounts for the variations in the gondola fleet as well. With two extremes of hopper length along with the unit coal-train car, a large portion of the railroad car fleet is represented.

The final car in the table is the TOFC car. This car is certainly a staple of the car fleet but the use of 286,000 may be considered questionable. The car type exists for that weight for use as a heavy-duty flatcar. Cars of this type are also in the railcar fleet with DODX reporting marks for shipment of military equipment.

### **Design Loadings**

Design loadings come from two sources. The Association of American Railroads (AAR) publishes minimum railcar length dimensions for design of new freight cars (6). The other source of loadings is the AREMA Manual.

The dimensions for the AAR design cars are listed in Table 2. These cars are designed on the basis of two criteria. The first criterion is that the axle spacings need to be such that the bending moment created on bridges of certain length does not exceed a certain level. The other criterion for these design car dimensions is that they fit within appropriate horizontal and vertical clearance envelopes.



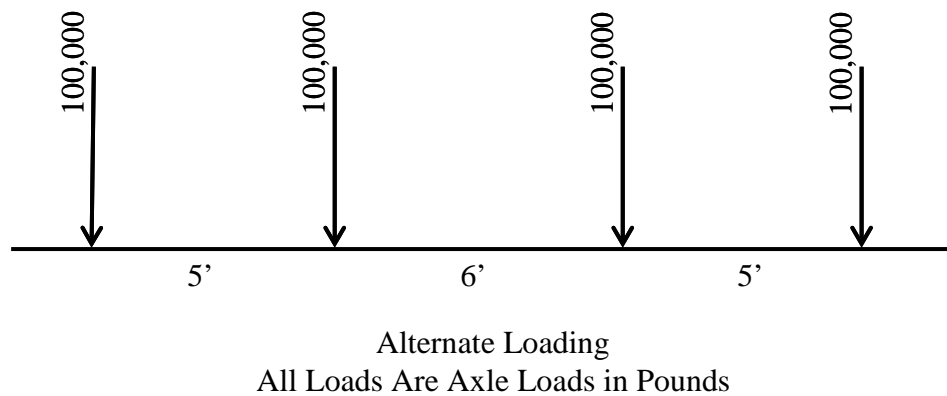
**TABLE 2. AAR Railcar Design Configurations (All Four-Axle Cars)**

Type	L <sub>O</sub>	S <sub>O</sub>	S <sub>I</sub>	S <sub>T</sub>	GW
AAR 1	41.96	6.71	23.58	5.83	286,000
AAR 2	41.92	7.71	22.54	5.83	286,000
AAR 3	41.88	8.71	21.50	5.83	286,000

The table shows that very little difference exists for these cars in overall length. The main difference in them is the spacing between the trucks. The first car has the trucks located toward the ends of the car as far as possible. The other cars are progressively shorter by a very small amount while shifting the trucks by a larger amount toward the middle of the cars. The shifting of the trucks toward the middle of the car helps lower the overall magnitude of maximum bending moment and is useful for the designation of axle spacings for lines where provisions may be needed to lower the overall maximum bending moment. Since these railcar configurations are the shortest lengths available to be able to weigh 286,000 pounds, they provide the highest equivalent unit weight per foot of loading for any interchange-acceptable railcar type.

The other loading that can be useful in development of a fatigue loading is the Alternate Loading contained in the AREMA Manual, shown in Chapter 15. The Alternate Loading (Figure 3) is used to develop higher bending moment magnitudes on short spans than can be developed using the standard Cooper E80 Loading. It is useful for floor systems in trusses and any short beam or girder spans less than approximately 50 feet long. What is unique about the Alternate Loading is that it does not represent a railcar per se; it represents the end of two cars with the coupling between the cars, providing the

dimensions  $S_O$  and  $S_T$  per the diagram in Figure 2. This arrangement of the axle loads creates the maximum moments on any short span length and it is a useful load for its purpose. In combination with the Cooper E80 Loading, the Alternate Loading can increase the size of floor system members (usually very short spans) while the Cooper E80 Loading is still sufficient for longer spans. The Alternate Loading can be used as a basis for a car configuration with the application of an  $S_I$  dimension to complete an entire car length.



**FIGURE 3. AREMA Alternate Loading**

From the variety of actual loadings along with those used for design purposes, options exist for creating a loading that can be used for fatigue analysis and design. The need is for a loading that can be effective in all design and rating circumstances should be reflective of the conditions shown in the actual and design loadings.

## **BENDING MOMENT BEHAVIOR OR RAILROAD LOADINGS**

Two distinct types of behavior in relation to fatigue loading exist for railroad loadings. In addition to the behavior displayed in Figure 1, some short spans are loaded in a manner similar to highway bridges. An examination of Table 2 shows the critical dimension  $S_I$ . When span lengths are less than that dimension, the bridge span is loaded in a fashion similar to highway bridges with a complete unloading of live load prior to the next load being applied. For fatigue analysis of this type of span, the appropriate analysis is determining how many axles may be loading the span at any particular time, find the maximum moment condition, and determine how many axle groups in any train may load the span during a train passage.

An examination of Table 2 shows that a span length of up to 60 feet may be subjected to this behavior depending upon the types of cars used on any particular rail line. For very short spans, the number of cycles may correlate to the number of trucks in the train, but for a slightly longer span the number may be closer to the number of railcars in the train instead. The moment range with a short span will be the maximum moment in these instances, with a need to analyze the number of cycles that may be loading the span during the train passage. The fatigue cycling in this case is directly related to the axle weights of the railcars. This moment range behavior is termed short span behavior in this study, but it is a function of the relation of the dimension  $S_I$  to the span length  $L_O$ . Depending upon the railcar, short span behavior can be experienced on span lengths from zero to 60 feet.

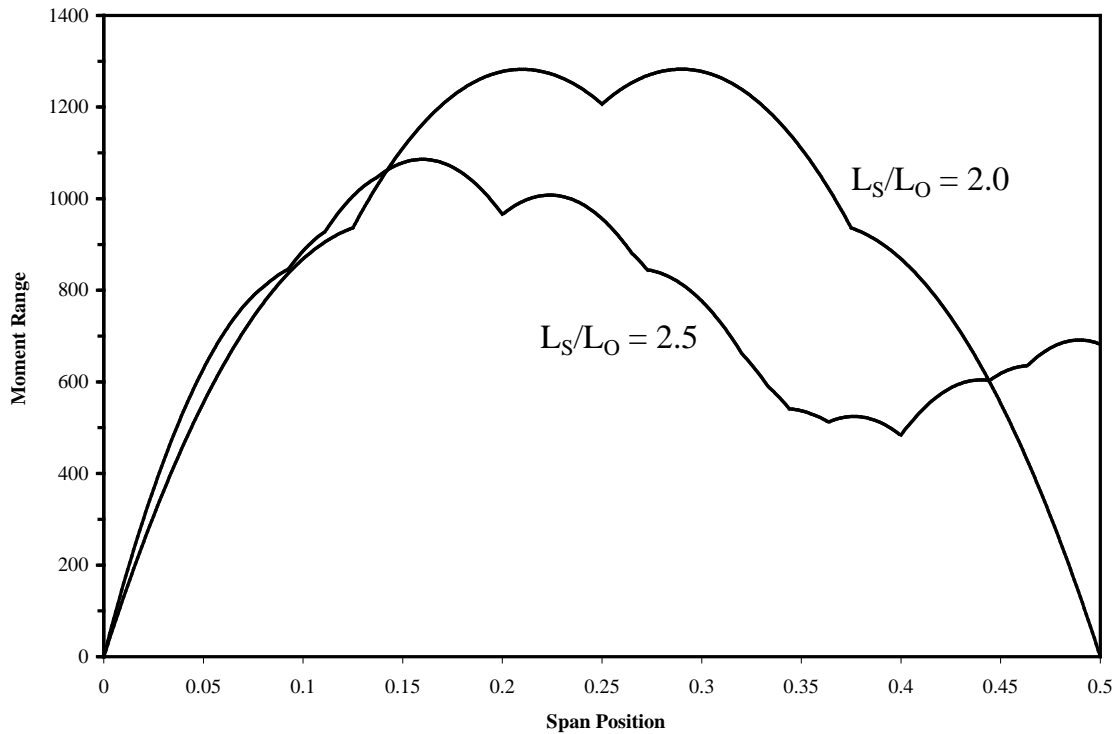
For the behavior displayed in Figure 1, the behavior is more complicated and depends upon the railcar dimensions along with the relationship between the length of the

span and the length of the railcar in use. This is known as the  $L_S/L_O$  ratio. The overall behavior of the loadings in this instance is termed long span behavior for the purposes of this research. In this loading regime, the bridge span is constantly loaded during a train passage with some loading pattern on the bridge at all times. From past research (7, and reported in 1), it is known that the moment range displayed by the repetition shown in Figure 1 has an absolute maximum for any railcar type, and that absolute maximum depends only upon the dimensions of the railcar itself. The formula for the absolute maximum moment range is:

$$R_{AM} = nP \left[ \frac{S_l}{4} - \frac{S_o}{4} + \frac{S_o^2}{4L_o} \right] \quad (1)$$

The dimensions for this formula are those defined in Figure 2. The actual magnitude of the maximum moment range for any given span length is dependent upon the value of the  $L_S/L_O$  ratio. For values of the ratio equal to integer values,  $R_{AM}$  is the absolute maximum. For values other than the absolute maximum, the value is obviously less than the absolute maximum, but does display predictable behaviors. The full discussion of that behavior is beyond the scope of this study. A full description of this is available in reference (6). For an example of this, Figure 3 displays the moment range behavior for the  $L_S/L_O$  ratios of 2.0 and 2.5 for the AAR1 railcar. The moment range for  $L_S/L_O = 2.0$  displays symmetrical behavior with the maximum points centered around the quarter points of the span with zero moment range at midspan. The moment range for  $L_S/L_O = 2.5$  does not possess the overall magnitude of the other curve, but moment range is significant when compared against the pure case of the integer value of  $L_S/L_O$ .

A critical point for moment range is that a maximum value will occur somewhere on the span. Even if the absolute maximum is not generated for  $L_S/L_O = 2.5$ , the value is not insignificant compared to the absolute maximum, so moment range can occur at critical locations such as cover plate cutoffs.



**FIGURE 3. Moment Range Versus Span Position for the AAR 1 Railcar.**

Additional information is provided by Table 3. This table uses the dimensional data from Table 2 to provide an idea of what the potential moment range is for each railcar type. In the table, a new reference name for maximum moment range is the Maximum Repetitive Moment. From this point, the moment range will be referred to as the repetitive moment as this is a bending moment that is repeated as each railcar in a unit train crosses a bridge span. In the fatigue analysis, the maximum moment will exist for the overall maximum

moment that occurs with moment behavior displayed in Figure 1, while each car will also create a repetitive moment that is the moment range, the difference between the maximum and minimum live-load moment. From Table 3, it should be noticed that there is no correlation between the weight per unit length of a rail car and its maximum repetitive moment. From Formula 1, it is seen that the high  $S_1$  value combined with a low  $S_0$  value are necessary conditions for a high repetitive moment. Overall weight simply has a linear magnification effect. With this in mind, a rational fatigue loading needs to account for the length effects with the axle weights serving to provide the necessary magnitude to encompass all conditions for fatigue design and rating of steel structures.

**TABLE 3. Comparison Of Uniform Loads And Maximum Repetitive Moments.**

Type	$L_0$	Equivalent Uniform Load (lb/ft)	Maximum Repetitive Moment (k-ft)
Six Axles Locomotive	74.00	5797	2,660.9
Four Axles Sand/Cement Hopper	41.96	6816	1,283.2
Coal	53.08	5388	2,057.4
Long Hopper	69.00	4145	3,186.7
TOFC	94.67	3021	3,063.1
AAR 1	41.96	6816	1,283.2
AAR 2	41.92	6823	1,161.9
AAR 3	41.88	6829	1,044.1

## **FATIGUE RAILCAR AND FATIGUE TRAIN DEVELOPMENT**

Given the information and data, a fatigue railcar and train should have certain characteristics that will allow for general use for both rating and design:

1. Possess a relatively high magnitude of repetitive moment.
2. Should have sufficient overall maximum moment so that it works for both maximum moment fatigue analysis as well as repetitive moment capability.
3. Needs to resemble actual equipment in its configuration.
4. Should have simple dimensions for simplicity of calculation.

The AREMA Alternate Loading presents a basis for which to develop the fatigue car. Its loading resembles the ends of two cars while having simple dimensions and realistic axle loadings. The Alternate Loading has to be combined with an  $S_I$  dimension in order to complete the full railcar configuration. The dimensions provided in Table 1 show that a dimension of 60 feet is prevalent in the railcar fleet given the high number of TOFC flatcar platforms and the increasing lengths of covered hoppers and tank cars. This length provides for any girder span length up to 60 feet to be controlled by maximum moment generated by the Alternate Loading arrangement with span lengths in excess of 60 feet taking advantage of repetitive moment theory.

The axle weights are an area that can be adjusted. For the purposes of this study, the usual axle weight for the Alternate Loading of 100,000 pounds per axle has been reduced to 80,000 pounds per axle and some additional data development with 71,500 pounds per axle was also done. The 71,500-pound axle reflects a maximum allowable axle load for unrestricted interchange while 80,000 pounds per axle mirrors the Cooper E80 Loading. It is also a reflection that fatigue loadings do not need to represent the

heaviest equipment but need to be close to the actual conditions experienced in the current operating environment. Table 4 and 5 present the length and weight dimensions for the proposed fatigue loading along with its maximum repetitive moment.

The fatigue car loading is scalable similar to the Cooper E Loading. The fatigue loading is referred to here as the Fatigue 80, or F80. The F80 train is composed of 100 F80 railcars; that number of cars chosen for mathematical expediency. It is also a plausible number for the total number of railcars and locomotives in a train. Total weight of the train is 16,000 tons, approximating a unit coal or grain train.

**TABLE 4. Proposed Fatigue Car Dimensions (Four-Axle Cars)**

Type	L <sub>O</sub>	S <sub>O</sub>	S <sub>I</sub>	S <sub>T</sub>	GW
Fatigue 80 (F80)	76.00	6.00	60.00	5.00	320,000
Fatigue 71.5 (F71.5)	76.00	6.00	60.00	5.00	286,000

**TABLE 5. Comparison of Uniform Loads and Repetitive Moments.**

Type	L <sub>O</sub>	Equivalent Uniform Load (lb/ft)	Repetitive Moment (k-ft)
Fatigue 80 (F80)	76.00	4211	4,357.9
Fatigue 71.5 (F71.5)	76.00	3763	3,894.9

For span lengths 60 feet or less, the Alternate Loading axle group controls the number of cycles and the fatigue stress ranges by the magnitude of the maximum moment. Once the span length is increased over 60 feet, repetitive moments enter into the

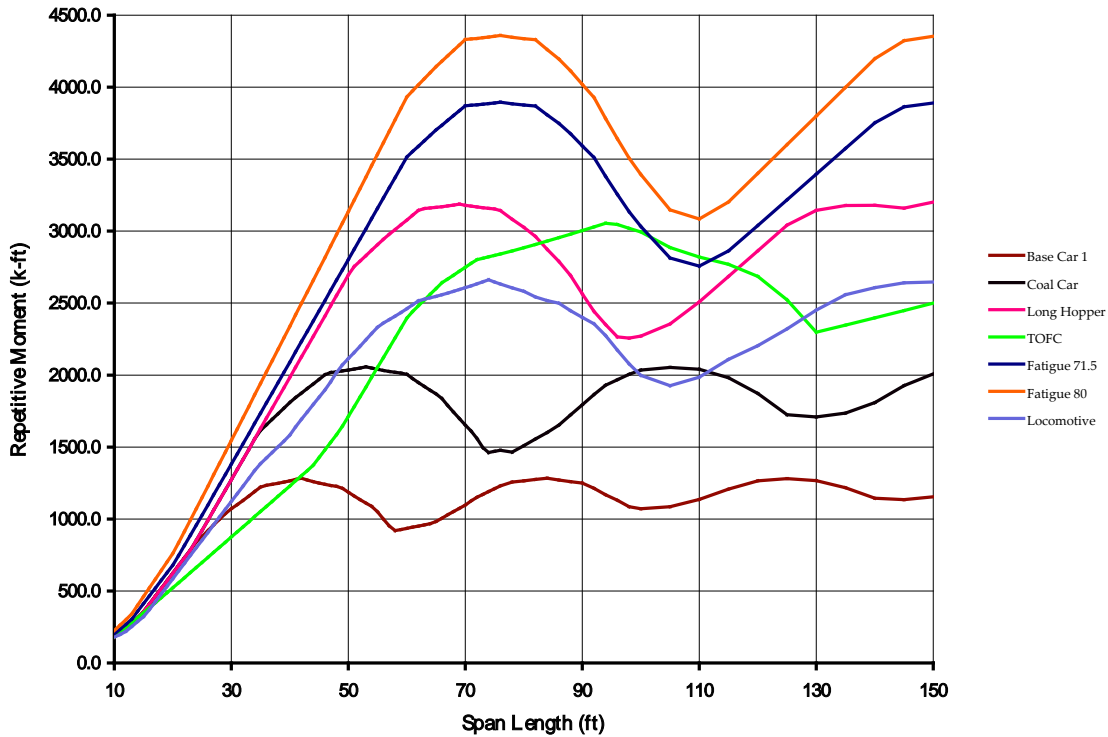


calculations. The value of the absolute maximum repetitive moment is attained when  $L_S/L_O = 1.0$ , or 76 feet for the F80 railcar. From earlier discussion and Figure 3 it is known that the repetitive moment will vary due to the actions of the loading and the  $L_S/L_O$  ratio.

A departure from the theory is taken at this point for the application of the repetitive moment. Above a span length of 76 feet, the actual value of repetitive moment has been replaced with the maximum value of repetitive moment. The reason for this is two-fold: 1) if attempting to calculate additional values for different span lengths the use of the absolute maximum repetitive moment does not require determining the exact maximum repetitive moment, and 2) while it is correct to have lesser values of repetitive moment for longer span lengths according to the theory, the application of the Root Mean Cube (RMC) to the maximum and repetitive moments can create lower RMC moment values for longer span lengths. While correct, it appears counterintuitive. This modification will ensure that as span lengths increase, the magnitude of the RMC moment will also increase. Figure 4 provides a view of the variation in repetitive moments for the railcars over the range of span lengths.

The F80 train was tabulated for a variety of span lengths, some of which are shown in Table 6. Each span length was examined for the overall number of expected cycles and a RMC moment was calculated for each span length. The RMC moment was then converted to normalize all of the moment values for 100 cycles, conforming to one cycle per car of the F80 train. The values provided for both F80 and F71.5 trains in Table 6 are for the normalized RMC moments. Additionally, some minor moment cycles were

taken into account for the beginning and ending of the train on shorter span lengths. Those moment values are not included in the table.



**FIGURE 4. Repetitive Moment Versus Span Length for Railcars**

A comparison of both maximum moments and repetitive moments provide insights into how the railcars are more effective on some span lengths versus others. The same holds true for RMC moments, especially when taking into account the effects of normalizing for the number of cycles that are expected. The comparison is displayed in Figure 5 through Figure 8.

Figure 5 displays the maximum moment for each railcar type in terms of a Cooper E Rating. The figure displays predictable results in that the cars with the closest axle spacings govern on short span lengths while the shorter cars with higher equivalent

uniform weights govern on the longer spans. Although the locomotive is the heaviest equipment, the wider axle spacings and its overall length control over only a narrow segment in the 65- to 85-foot span length range.

Figure 6 shows the variation in repetitive moment versus span length and shows much the opposite behavior of Figure 5. The coal car and the AAR 1 car both decrease quickly and the longer cars show the influence of the longer  $S_1$  dimension. Even with that, no repetitive moment on actual equipment exceeds Cooper E10 in magnitude for the extremely long span lengths.

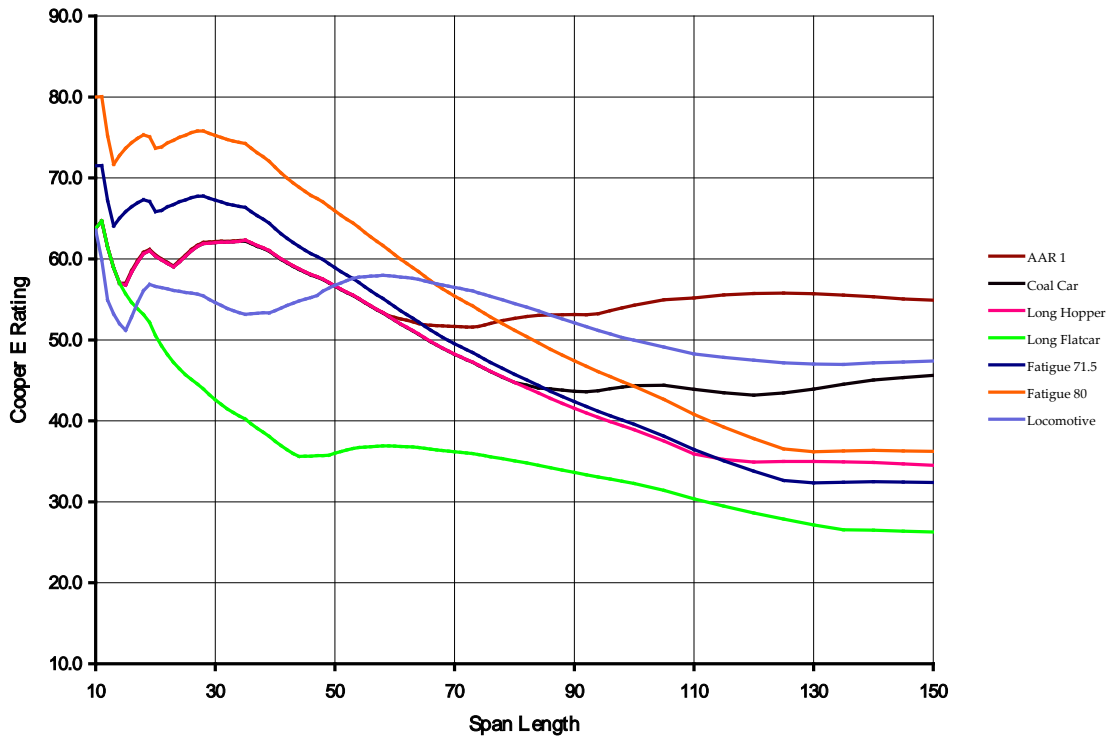
Figure 7 shows the tabulations of RMC moment for the individual railcars. What is obvious is that the locomotive has an overall high RMC moment when compared to the other equipment. This is somewhat deceiving as the locomotive does have a high maximum moment, but with few repetitive cycles given that only a few locomotives are needed per train. This skews the RMC moment in comparison to the other railcars shown.

Figure 8 provides another perspective to what is shown in Figure 7. Figure 8 displays the results for the normalization process which provides an idea of the damage potential for an equal number of cycles for each piece of railcar equipment.

The locomotive, when normalized to the same number of cycles as the F80 railcar, shows a much lower overall damage potential. Given the low number of locomotives compared to the amount of freight railcar equipment, the lower level of damage potential is not unexpected. Figure 8 shows some potential anomalies where abrupt changes in the plots occur for some equipment. This is evident in the locomotive and TOFC graph lines. This is a result of those regions where a change in the number of cycles occurs and the result is affected by the normalization calculation.

**TABLE 6. RMC Moments for F80 and F71.5 Trains**

Span Length (ft)	Maximum Moment (k-ft)	Repetitive Moment (k-ft)	F80 Train RMC Moment	F71.5 Train RMC Moment
12	300.8		379.0	338.8
16	520.4		521.0	465.7
20	760.3		760.4	679.7
24	1070.0		1069.1	955.5
28	1385.7		1383.9	1236.8
32	1702.5		1699.8	1519.2
36	2020.0		2016.4	1802.2
40	2338.0		2333.6	2085.6
44	2656.4		2651.1	2369.4
48	2975.0		2968.9	2653.5
52	3293.8		3287.0	2937.7
56	3612.9		3605.2	3222.1
60	3932.0		3923.5	3506.6
64	4251.3	4100.0	4101.6	3665.8
68	4570.6	4254.4	4257.8	3805.4
72	4890.0	4337.8	4344.0	3882.5
76	5209.5	4357.9	4368.2	3904.0
80	5529.0	4357.9	4373.0	3908.4
84	5848.6	4357.9	4378.4	3913.2
88	6168.2	4357.9	4384.4	3918.6
92	6487.8	4357.9	4391.0	3924.5
96	6807.5	4357.9	4398.4	3931.0
100	7127.2	4357.9	4406.4	3938.2
105	7526.9	4357.9	4417.4	3948.0
110	7926.5	4357.9	4429.6	3959.0
115	8326.3	4357.9	4443.0	3970.9
120	8726.0	4357.9	4457.7	3984.1
125	9125.8	4357.9	4473.7	3998.3
130	9747.7	4357.9	4501.2	4022.9
135	10506.7	4357.9	4539.3	4057.0
140	11268.6	4357.9	4582.7	4095.8
145	12033.1	4357.9	4631.6	4139.5
150	12800.0	4357.9	4686.1	4188.2



**FIGURE 5. Maximum Moment (Cooper E Rating) Versus Span Length**

One consistency displayed in Figure 5 through Figure 8 is the shape of the curve for the proposed F80 train. In addition to having a consistent shape for the different graphs, it displays the maximum behavior for RMC moments and normalized RMC moments. This is an important attribute when attempting to develop a reference loading. The use of RMC moments is critical in that the various fatigue cycle magnitudes must be combined mathematically in order to match the fatigue curves for the various categories. With the logarithmic slope of -3 for those curves, the RMC moment provides the correct mathematical combination for the fatigue cycles. The final item necessary for the development is testing against bridge configurations to see if the fatigue life is controlled by the F80 train so that it can be an adequate reference.

## VERIFICATION TESTING

The F80 train was tested against the other railcars in train configurations to ensure that the proposed fatigue loading would be adequate to cover different train types and lengths. Actual plans were available for span lengths of 29, 45, 49, 57, 58, 67, 78, 105, and 125 feet. The F71.5 train was also compared in limited testing to examine its applicability.

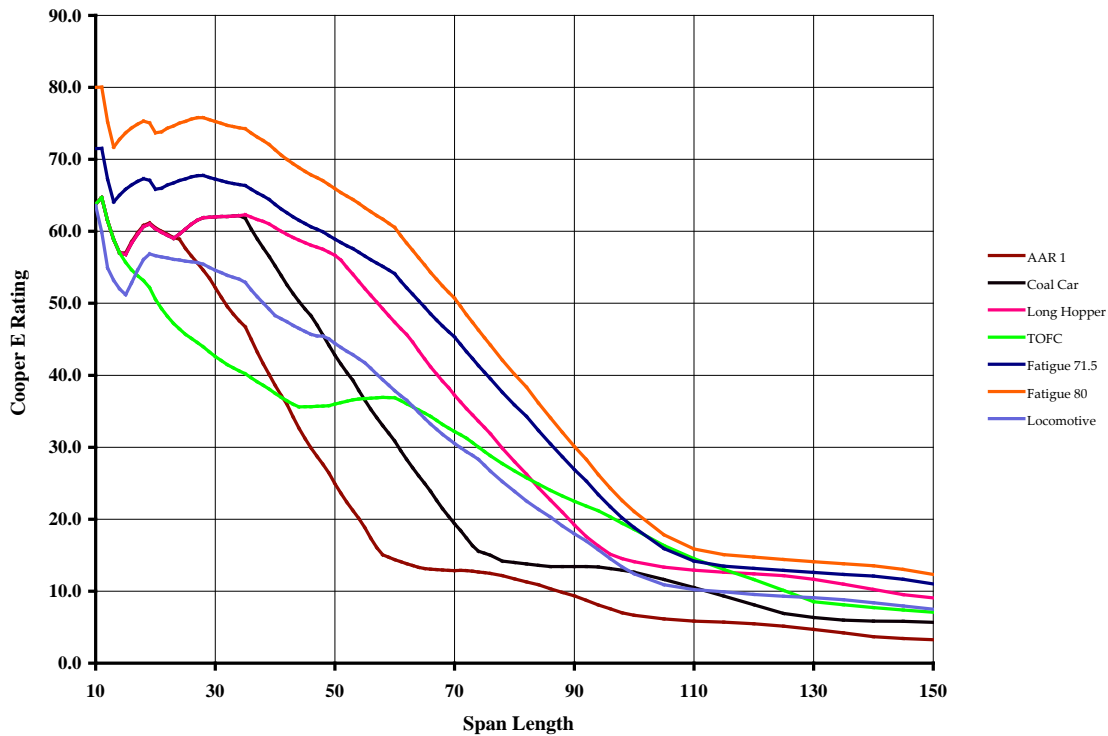
The following trains were used in the comparison:

F80:	100 railcars
AAR 1:	Three locomotives and 60 railcars
Coal:	Three locomotives and 150 railcars
Long Hopper:	Three locomotives and 60 railcars
TOFC:	Three locomotives and 100 railcars

The AAR 2 and AAR 3 railcars were eliminated from further consideration for analysis. Their dimensions were so close to AAR 1 that no benefit was derived from them. Even with the shorter length and higher unit weight for AAR 3, its effects on maximum moment were less than the AAR 1 car for all span lengths examined under 150 feet. This provides evidence of the influence of the close spacings of the axles at the ends of the cars as displayed by AAR 1, Coal, and Long Hopper railcars.

The calculations for the trains took into account the total number of expected cycles along with calculating an RMC moment for each. The RMC moments for the trains were not normalized as this step was not needed for this analysis. The estimated cycle life for Category D was calculated for both RMC stresses (and the total number of train cycles) along with checking the maximum stress only (one cycle on the applicable bridges where repetitive moments would apply). From the estimated cycle life, the train

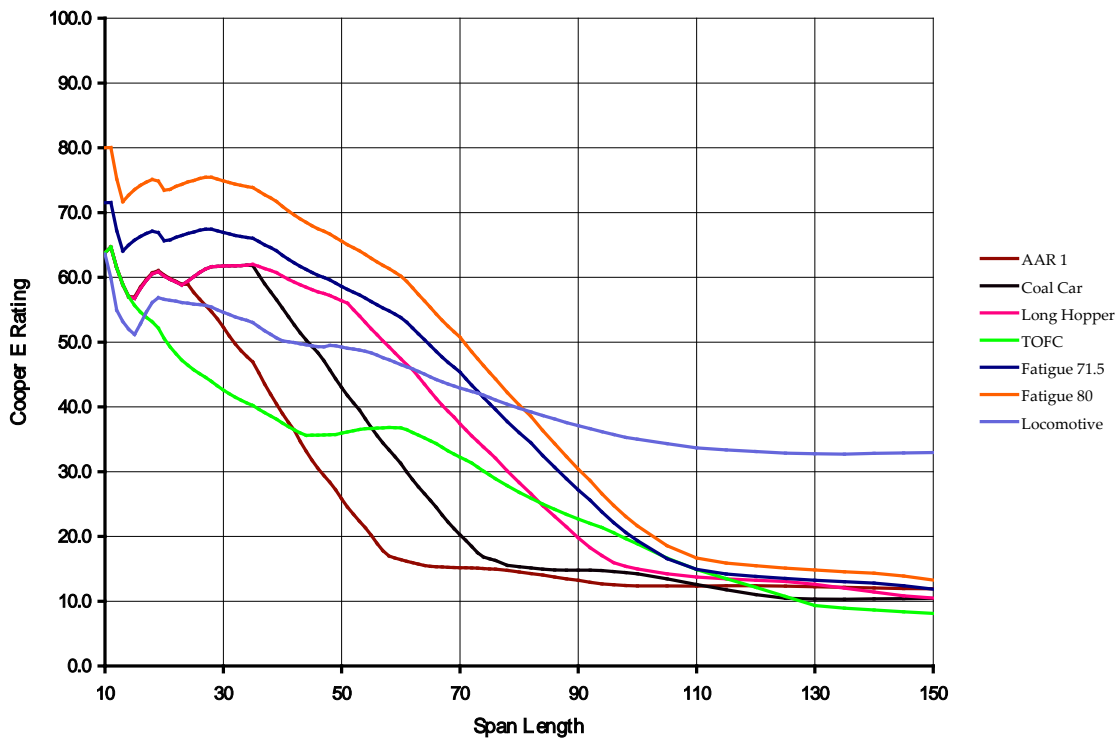
life was calculated based on the number of cycles per train. In all instances, the RMC stress range due to the maximum and repetitive moments controlled the train life calculations. The results are shown in Tables 6 and 7.



**FIGURE 6. Repetitive Moment (Cooper E Rating) Versus Span Length**

From an examination of the findings in Table 6 in comparison to Table 7, the train lives of the bridges based on maximum moment are much higher than those for the RMC moment. A close examination of Table 6 shows that the train life based on maximum moment for the longer spans are the same for the Long Hopper and the TOFC train. This is due to the maximum moment of the locomotive controlling versus any effect of the axle spacings on the ends of the cars are close to identical. Given the repetitive moments

shown in Figure 6 and in Table 3 it seems unlikely that the individual cars would not have some effect on train life of the bridges. For maximum moment, the F80 train does not control the train life for the 67-foot span. It is controlled by AAR 1 and Coal trains, and this is a measure of how the maximum moment for those cars exceeds the proposed F80 loading. To make the F Loading be the controlling load, it needs to be set at F90 when examining maximum moment only.

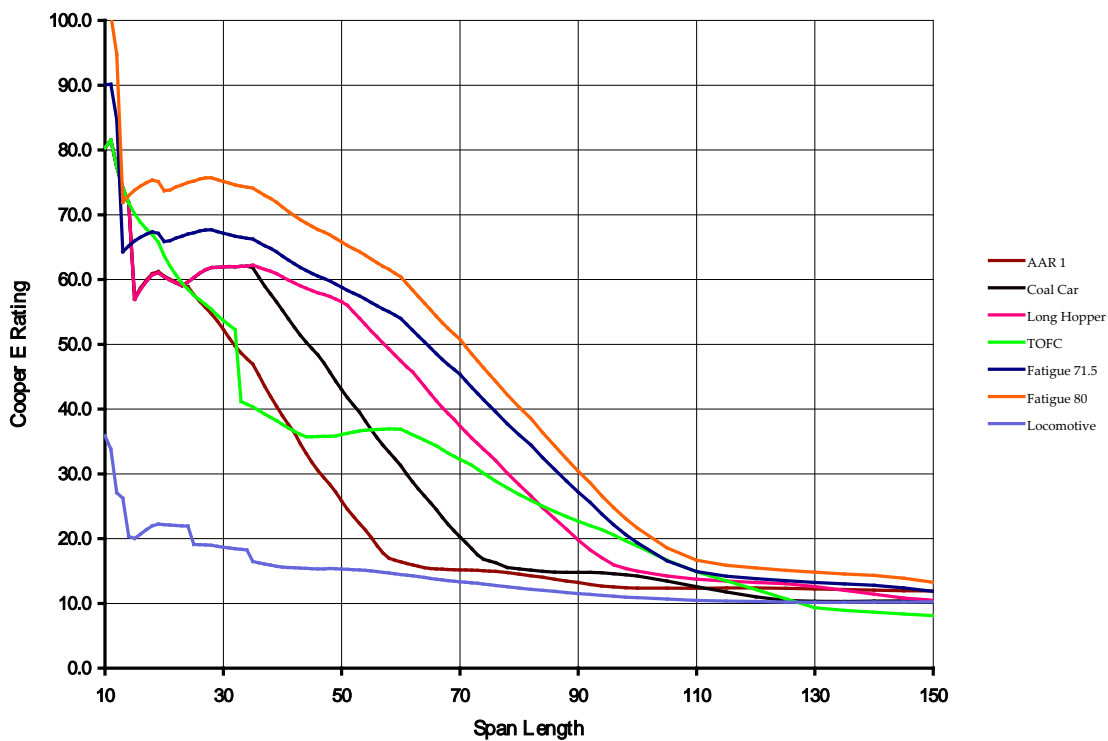


**FIGURE 7. RMC Moment (Cooper E Rating) Versus Span Length**

Table 7 provides the expected smaller estimated train life taking into account the number of cycles per train. The train lives are certainly more conservative using the repetitive cycles and it highlights the potential differences between the various railcar



types. For this analysis, the F80 train controlled the estimated train lives for all tested span lengths with the shortest span (29 feet) showing the closest relativity between the proposed loading and actual loadings. This is not unexpected as a span of this length is still under the influence of the magnitude of axle loads to a certain extent, with the Coal train closest in magnitude to F80. This seems reasonable as a 29-foot span is still short enough for the Coal car, Long Hopper, and F80 car that the maximum moment for the trucks at the car ends is the moment range as well. The difference in train lives between these cars is the number of cycles per train.



**FIGURE 8. Normalized RMC Moment (Cooper E Rating) Versus Span Length**

**TABLE 6. Calculated Train Lives for Maximum Moment - Category D**

Span Length	Train Life for Maximum Moments				
	AAR 1	Coal	Long Hopper	TOFC	Fatigue 80
29	38,525,471	38,779,295	211,523,426	302,474,036	21,419,978
45	29,935,705	29,935,713	163,285,709	195,290,130	18,695,420
49	15,289,008	15,289,012	83,394,611	86,401,237	9,681,984
57	25,201,220	25,201,220	137,461,202	137,461,202	20,365,711
58	12,279,416	12,279,416	66,978,630	66,978,630	10,195,040
67	57,490,754	57,490,754	313,585,930	313,585,930	57,927,910
78	10,355,839	10,355,839	56,486,394	56,486,394	12,220,644
105	6,970,580	9,763,496	53,255,431	53,255,431	14,920,781
125	5,685,801	9,408,088	51,316,845	51,316,845	20,244,501

**TABLE 7. Calculated Train Lives for RMC Moment - Category D**

Span Length	Train Life for RMC Moments				
	AAR 1	Coal	Long Hopper	TOFC	Fatigue 80
29	897,961	252,575	610,355	537,425	215,107
45	2,610,649	326,948	883,190	1,260,880	188,075
49	1,838,635	214,254	452,908	593,789	97,418
57	7,759,485	777,858	625,263	939,104	204,970
58	4,132,854	417,076	322,584	457,090	102,610
67	25,426,293	5,275,467	2,584,172	2,597,917	698,225
78	5,362,465	2,688,988	963,935	739,876	226,588
105	6,301,336	3,242,774	4,407,261	2,085,922	738,129
125	5,366,026	6,313,836	4,618,488	4,717,789	1,718,358

Table 7 provides the expected smaller estimated train life taking into account the number of cycles per train. The train lives are certainly more conservative using the repetitive cycles and it highlights the potential differences between the various railcar types. For this analysis, the F80 train controlled the estimated train lives for all tested span lengths with the shortest span (29 feet) showing the closest relativity between the proposed loading and actual loadings. This is not unexpected as a span of this length is

still under the influence of the magnitude of axle loads to a certain extent, with the Coal train closest in magnitude to F80. This seems reasonable as a 29-foot span is still short enough for the Coal car, Long Hopper, and F80 car that the maximum moment for the trucks at the car ends is the moment range as well. The difference in train lives between these cars is the number of cycles per train.

The coal train was the controlling train for short spans if the F80 train was not considered, but the effects of length were evident for the lengths of span from 58 feet and above. The coal train serves a purpose for the short spans only, but when considering the effects of repetitive cycling the coal train is inadequate for spans beyond a  $L_S/L_O$  of 1.0. For girder bridges, normally considered up to a span length of 150 feet, the longer car provided F80 provides a more conservative value.

## **CONCLUSIONS AND RECOMMENDATIONS**

From this preliminary testing, the F80 Loading and F80 Train are solid starting points for the development of a unique loading for design and rating of a bridge for fatigue. The F80 railcar's dimensions are displayed in Table 4. Using this car in a train allows analysis for both maximum moment and repetitive moment that is experienced during a train passage. The F80 Loading is a separate loading from Cooper E80. Cooper E80 is still the preferred load for strength design of a girder bridge with its much higher moment magnitude. The Cooper E80 Loading is not suitable for a fatigue loading, but has been adjusted in the current Chapter 15 recommendations to reflect anticipated cycles. This lack of suitability prompted the development of the F80 Loading.

While the preliminary examination looks promising, more testing against actual bridge span plans is needed for train life calculations to ensure that the loading provides an upper envelope for design. For rating, the loading as is can be used for development of reference for any train type.

Additionally, more detail is preferable in the regions of transition for the number of axles loading a bridge span and creating the maximum moment. Hidden cycles of significant magnitude may exist for spans of transition length that may be loaded by either three axles or four at different stages of the train passage. The work will continue with more verification testing and examination of transition span lengths.

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# Comparison of Railcar and Bridge Design Loadings for Development of a Railroad Bridge Fatigue Loading

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# Purpose of the Research

- Develop a loading for fatigue
  - Useful for both design and rating
  - Useful for girders and trusses
  - Desire for realism in the loading

# Current Fatigue Loading

- Utilizes the unit-train coal car
- Widespread use of the car
- Use of maximum allowable car weight
- Used for all span lengths and types

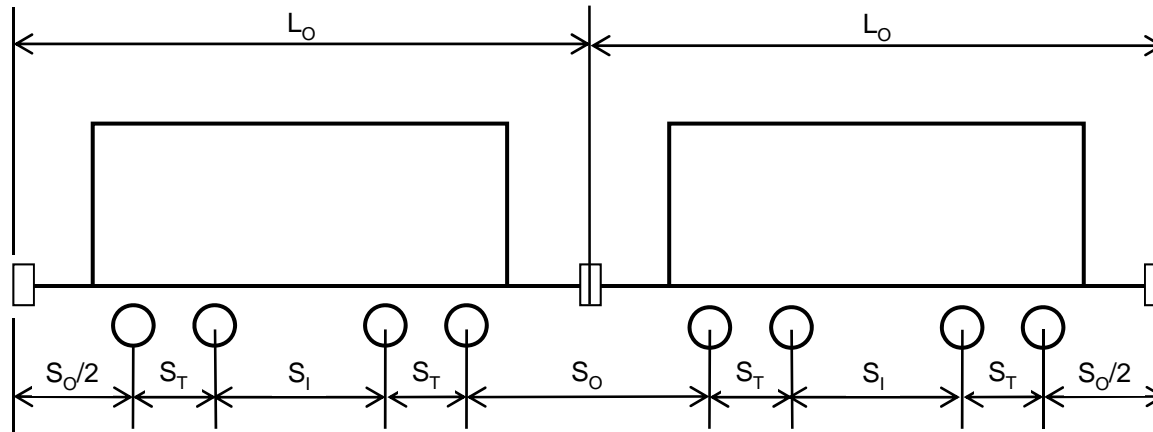
# Needs for a Fatigue Loading

- Needs to provide a reference level that translates between rating and design
- Needs to provide an envelope for design
- Needs to be a reference only for rating
- Desirable to account for stress and cycles

# Available Loading Criteria

- AREMA design loadings
- AAR design cars
- Actual loads (existing equipment)

# Typical Car Dimensions

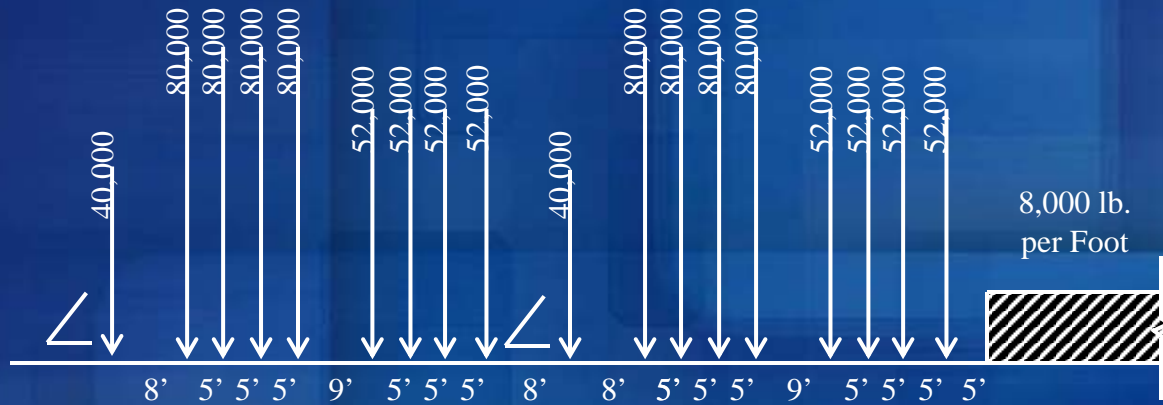


- $L_0$  - Overall length of railcar measured over the pulling face of the coupler
- $S_1$  - Inboard Axle Spacing, the distance between the inside axles of the railcar
- $S_0$  - Outboard Axle Spacing, the distance between the outside axles of the railcar
- $S_T$  - Truck Axle Spacing, the distance between the adjacent axles of a truck.
- $n$  - number of axles per railcar
- $P$  - axle load
- $GW$  - Gross Weight ( $nP$ )

# AREMA Design Loadings

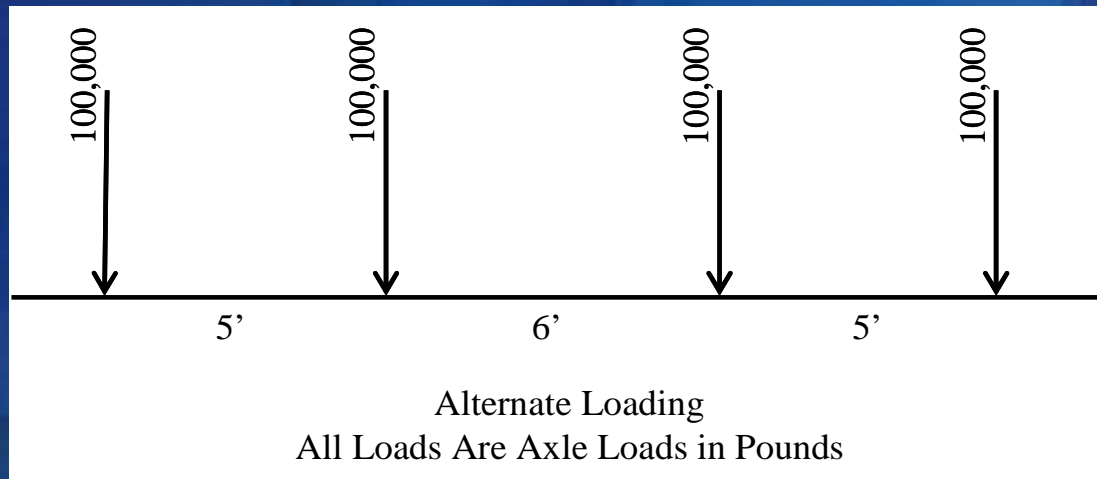
- Cooper E Loading
- Alternate Loading

# AREMA Design Loadings



Cooper E80 Loading  
All Loads Are Axle Loads in Pounds

# AREMA Design Loadings





# AAR Design Cars

**TABLE 2. AAR Railcar Design Configurations (All Four-Axle Cars)**

Type	L <sub>O</sub>	S <sub>O</sub>	S <sub>I</sub>	S <sub>T</sub>	GW
AAR 1	41.96	6.71	23.58	5.83	286,000
AAR 2	41.92	7.71	22.54	5.83	286,000
AAR 3	41.88	8.71	21.50	5.83	286,000

# Actual Loads

**TABLE 1. Dimensions For Locomotive and Railcars In This Study.**

Type	L <sub>O</sub>	S <sub>O</sub>	S <sub>I</sub>	S <sub>T</sub>	GW
Six Axles					
Locomotive	74.00	11.89	34.79	6.83	429,000
Four Axles					
Sand/Cement Hopper	41.96	6.71	23.58	5.83	286,000
Coal	53.08	6.75	34.67	5.83	286,000
Long Hopper	69.00	6.71	50.63	5.83	286,000
TOFC	94.67	22.83	60.17	5.83	286,000

# Behavior of Bending Moment

- Short Span Behavior

Bridges where span lengths are less than the dimension  $S_1$ .

- Long Span Behavior

Bridges where span lengths are greater than the dimension  $S_1$ .

# Bending Moment

## Short Span Behavior

- Fatigue cycles are directly dependent upon the magnitude of the axle loads
- Cycles consists of complete loading and unloading of a bridge by the grouping of axles near the coupling of the two cars
- Dimension  $S_1$  for cars is longer than the span length being crossed

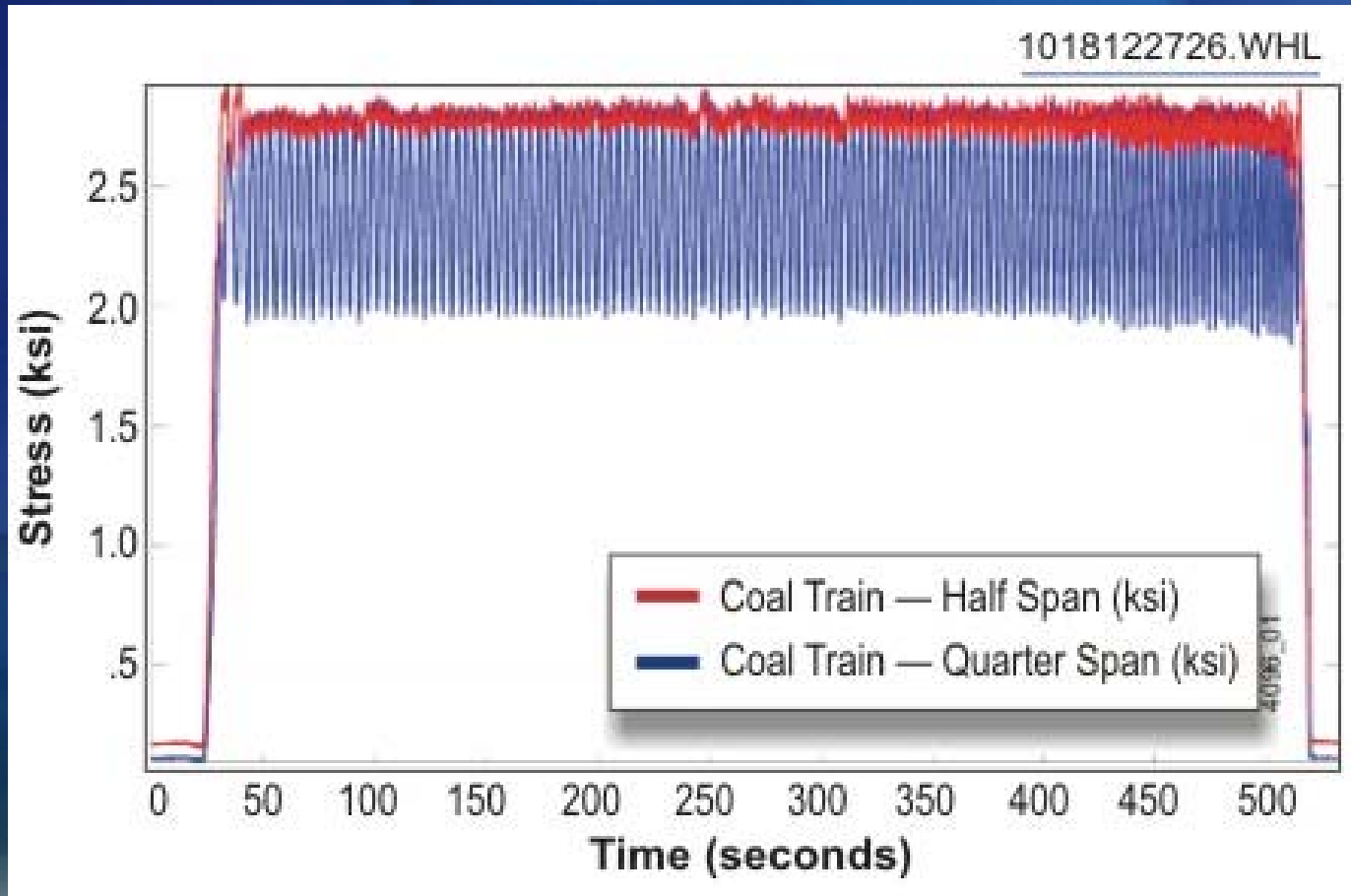
# Bending Moment

## Long Span Behavior

- Fatigue cycles are more sensitive to both axle loading and axle spacings
- Cycles consist of one maximum moment cycle and a series of repetitive cycles
- Dimension  $S_1$  for cars is less than the span length being crossed

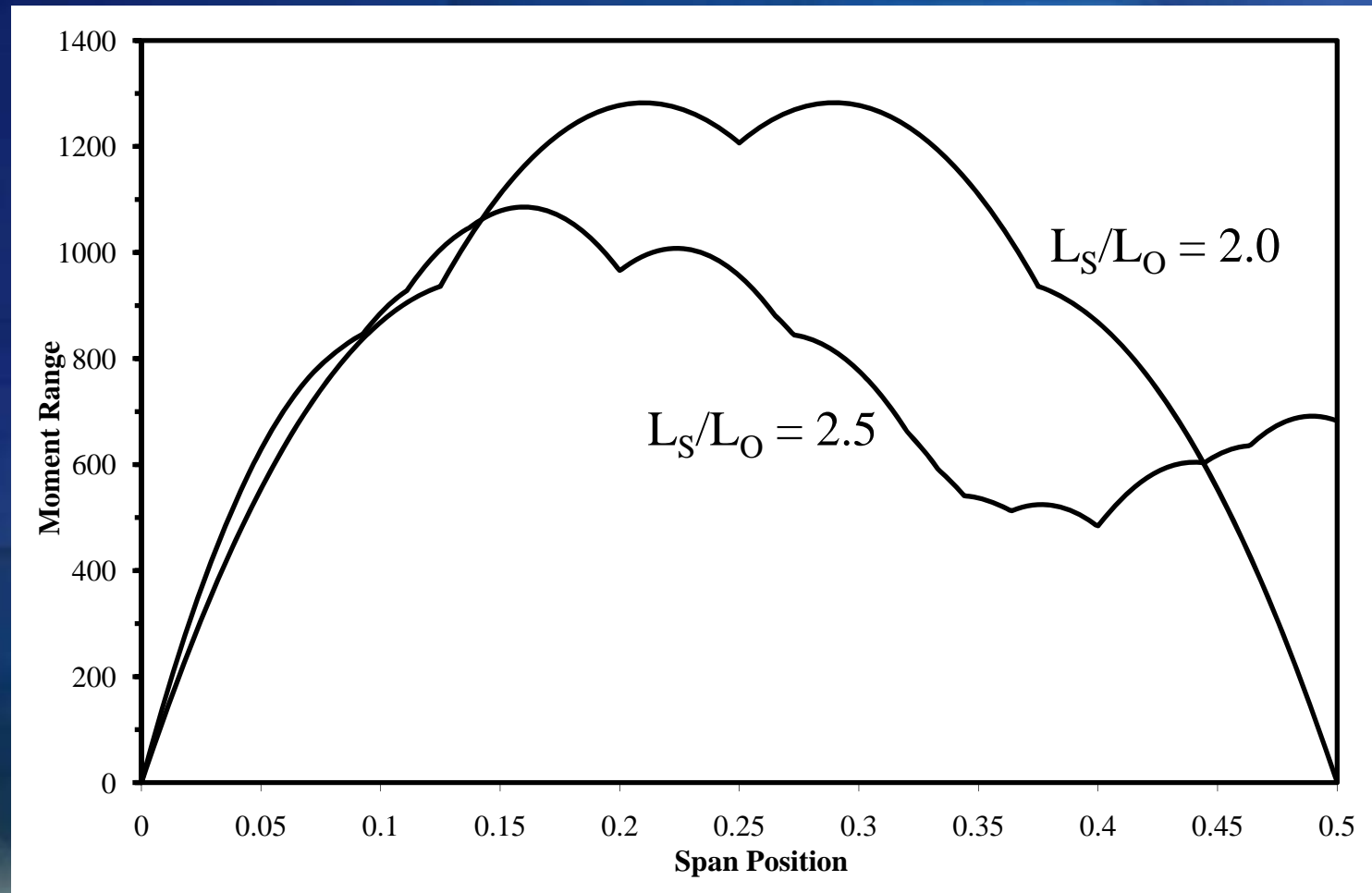
# Bending Moment

## Long Span Behavior



# Bending Moment

## Repetitive Moment



# Repetitive Moment

## Maximum Value Calculation

$$R_{AM} = nP \left[ \frac{S_I}{4} - \frac{S_o}{4} + \frac{S_o^2}{4L_o} \right]$$



# Repetitive Moment

**TABLE 3. Comparison Of Uniform Loads And Maximum Repetitive Moments.**

Type	$L_o$	Equivalent Uniform Load (lb/ft)	Maximum Repetitive Moment (k-ft)
Six Axles Locomotive	74.00	5797	2,660.9
Four Axles Sand/Cement Hopper	41.96	6816	1,283.2
Coal	53.08	5388	2,057.4
Long Hopper	69.00	4145	3,186.7
TOFC	94.67	3021	3,063.1
AAR 1	41.96	6816	1,283.2
AAR 2	41.92	6823	1,161.9
AAR 3	41.88	6829	1,044.1

# Proposed F80 Fatigue Car

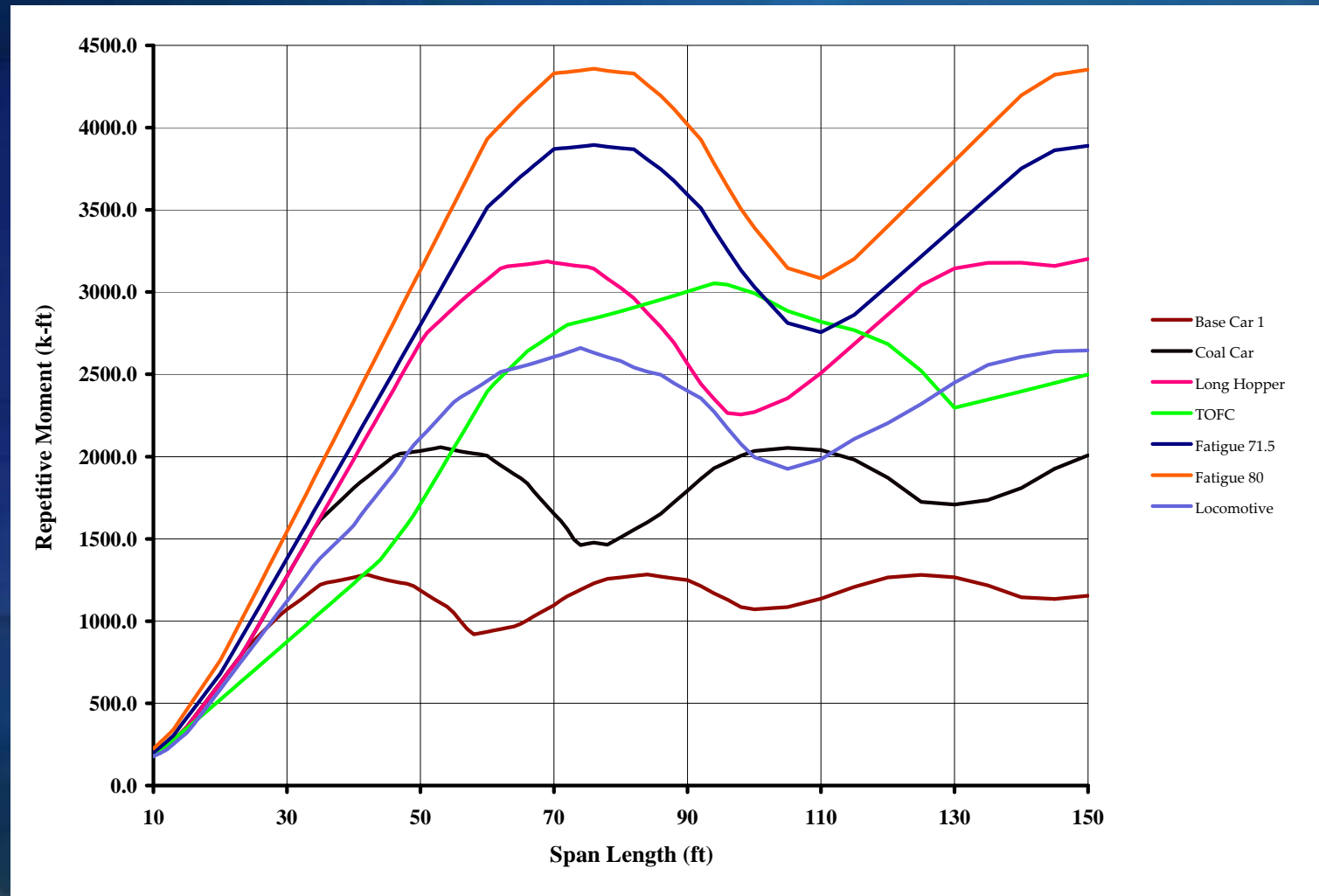
**TABLE 4. Proposed Fatigue Car Dimensions (Four-Axle Cars)**

Type	L <sub>O</sub>	S <sub>O</sub>	S <sub>I</sub>	S <sub>T</sub>	GW
Fatigue 80 (F80)	76.00	6.00	60.00	5.00	320,000
Fatigue 71.5 (F71.5)	76.00	6.00	60.00	5.00	286,000

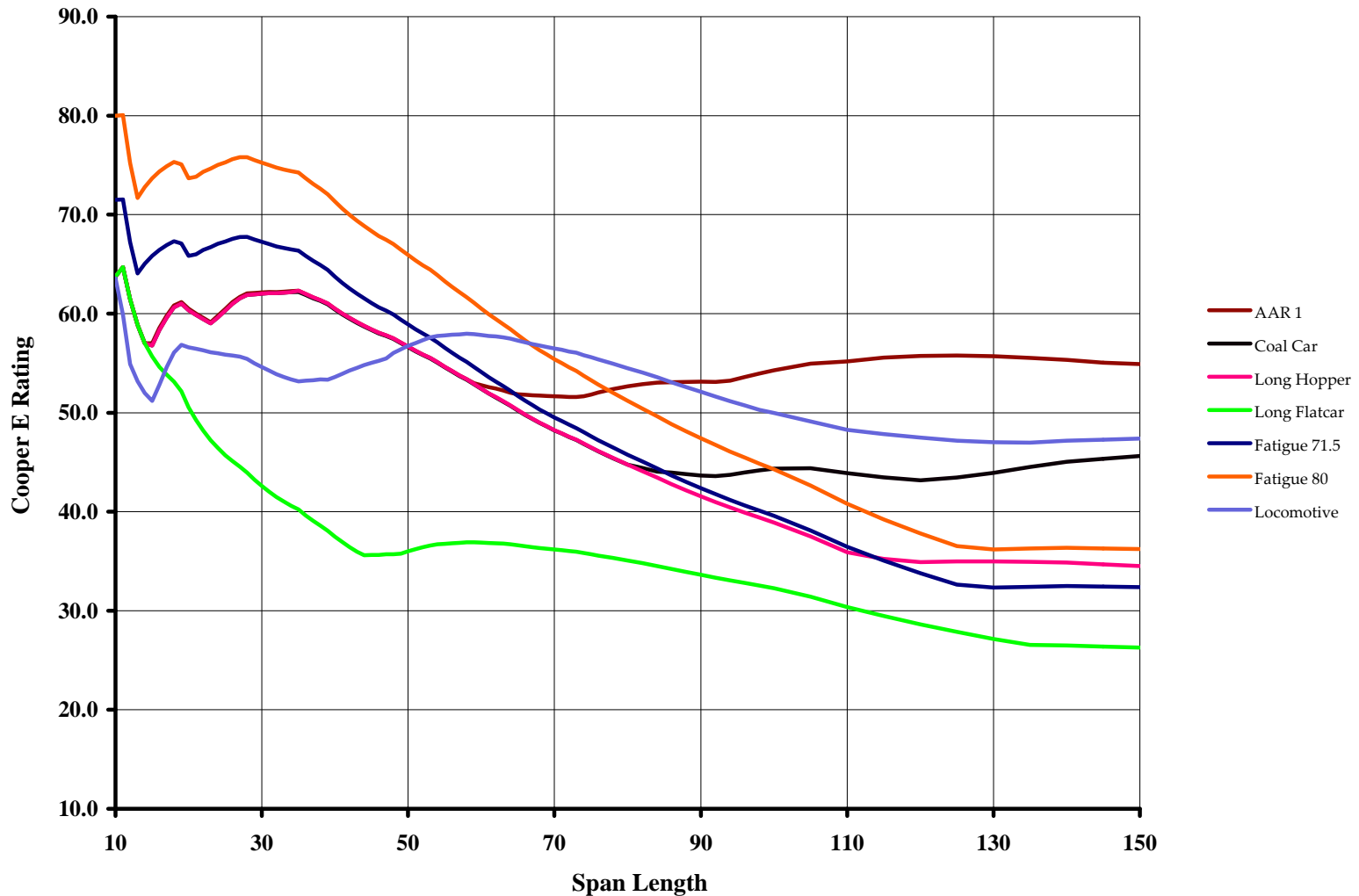
**TABLE 5. Comparison of Uniform Loads and Repetitive Moments.**

Type	L <sub>O</sub>	Equivalent Uniform Load (lb/ft)	Repetitive Moment (k-ft)
Fatigue 80 (F80)	76.00	4211	4,357.9
Fatigue 71.5 (F71.5)	76.00	3763	3,894.9

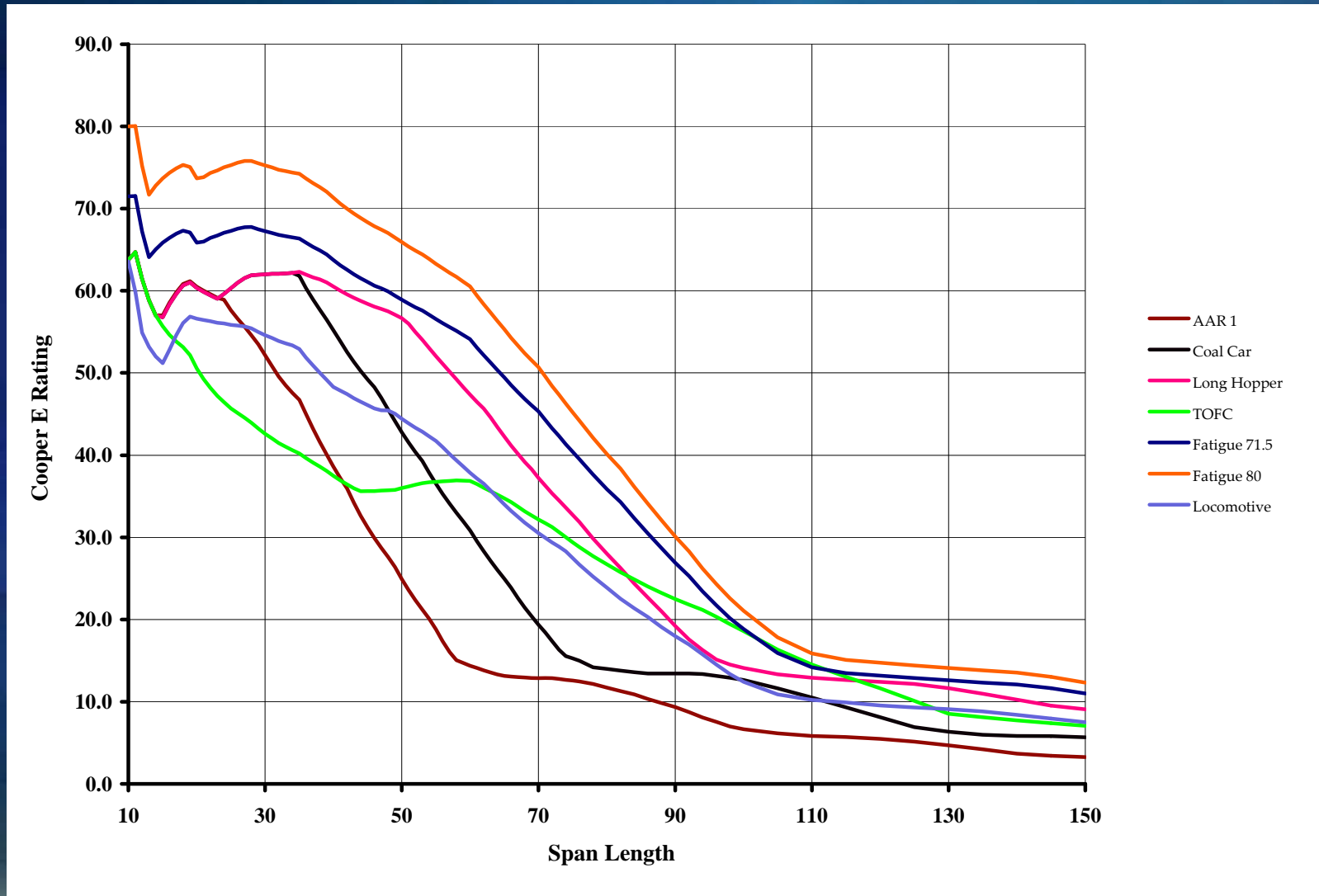
# Repetitive Moment Comparison



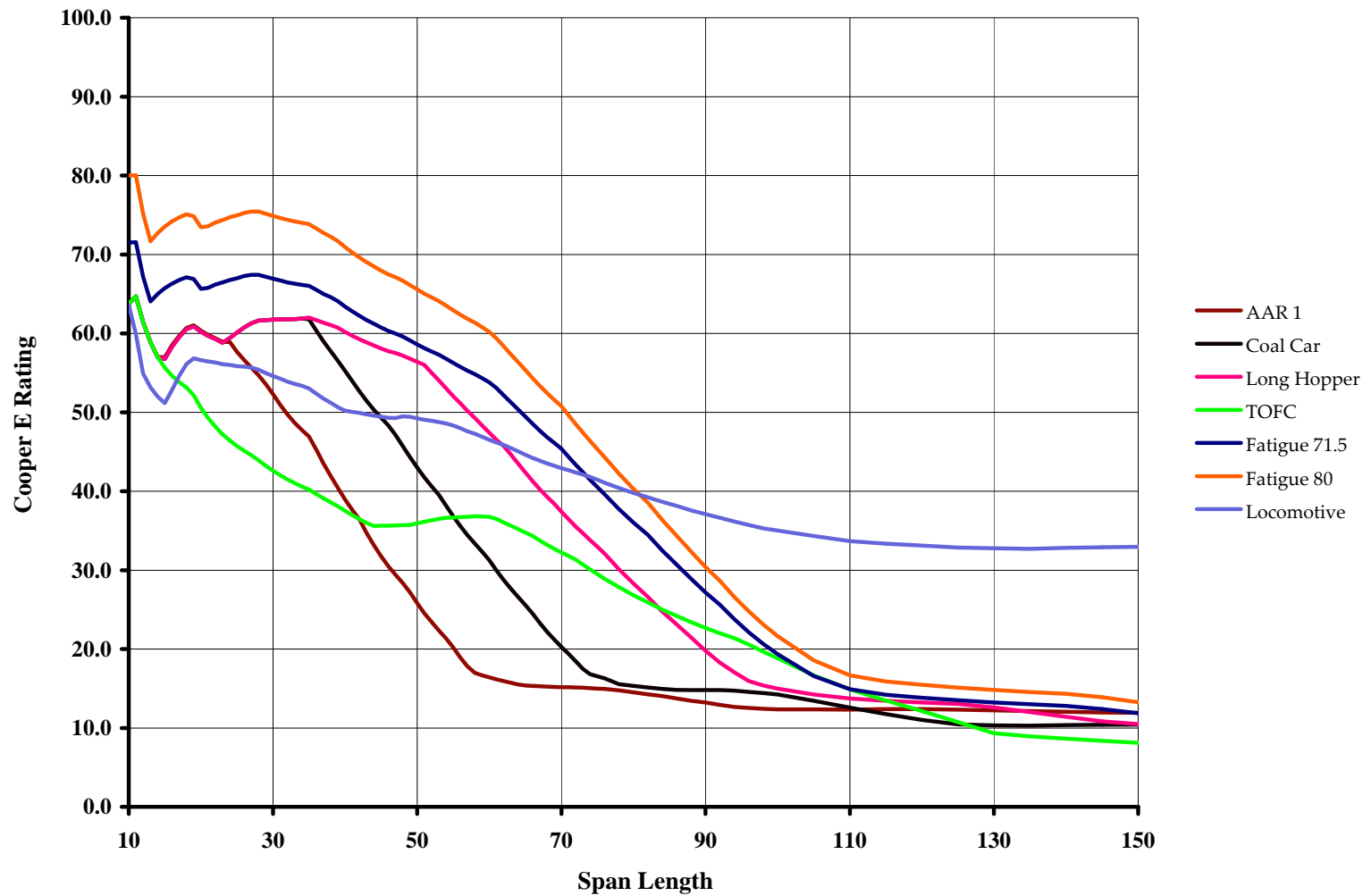
# Maximum Moment Comparison



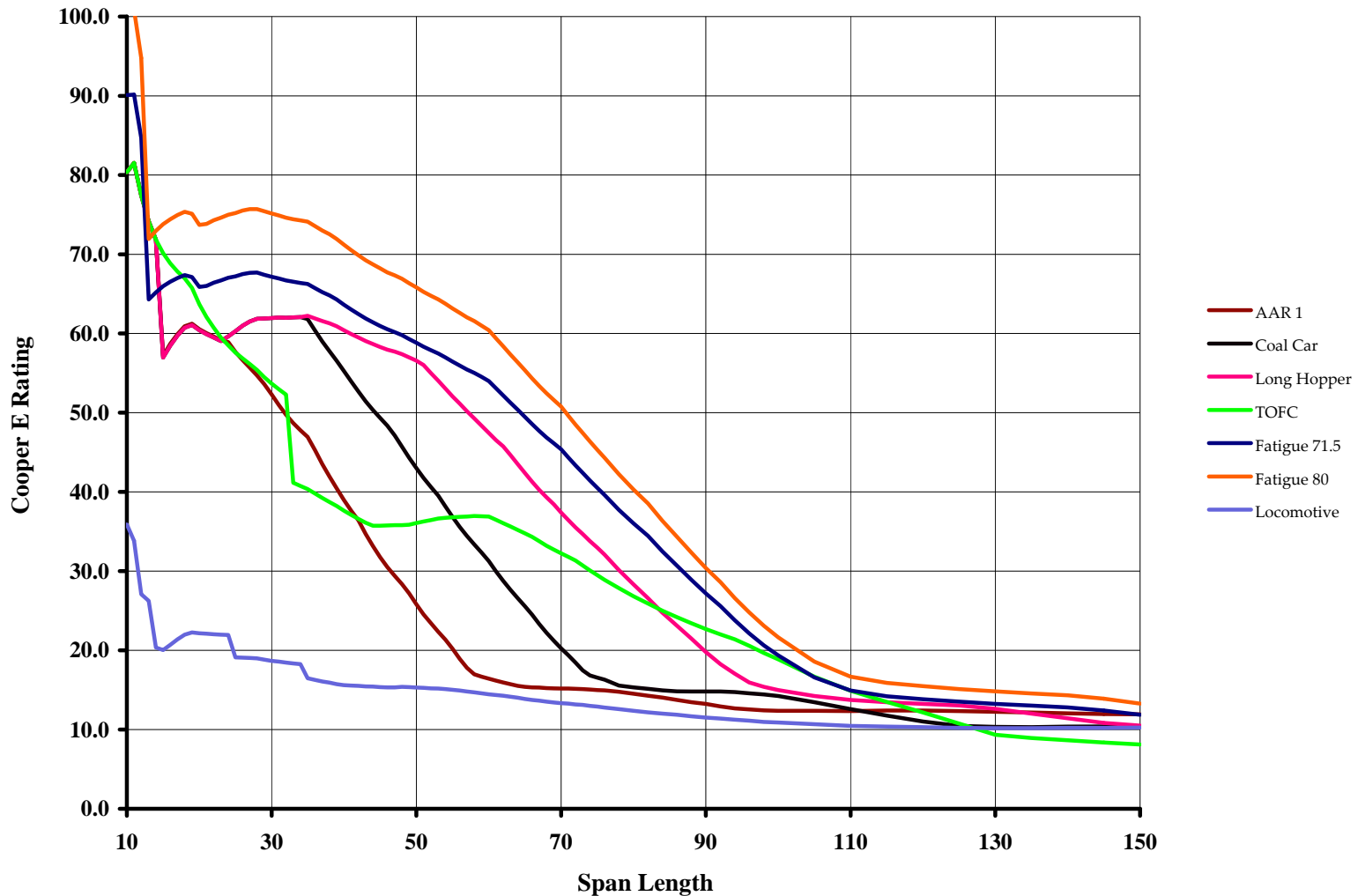
# Repetitive Moment Comparison



# RMC Moment Comparison



# Normalized RMC moment



# Formal Model for F80 Loading

- Utilize the F80 railcar with  $L_0 = 76.0$  feet
- Utilize 100 railcars for fatigue train
- Where Long Span Behavior is exhibited, always use the maximum magnitude of Repetitive Moment



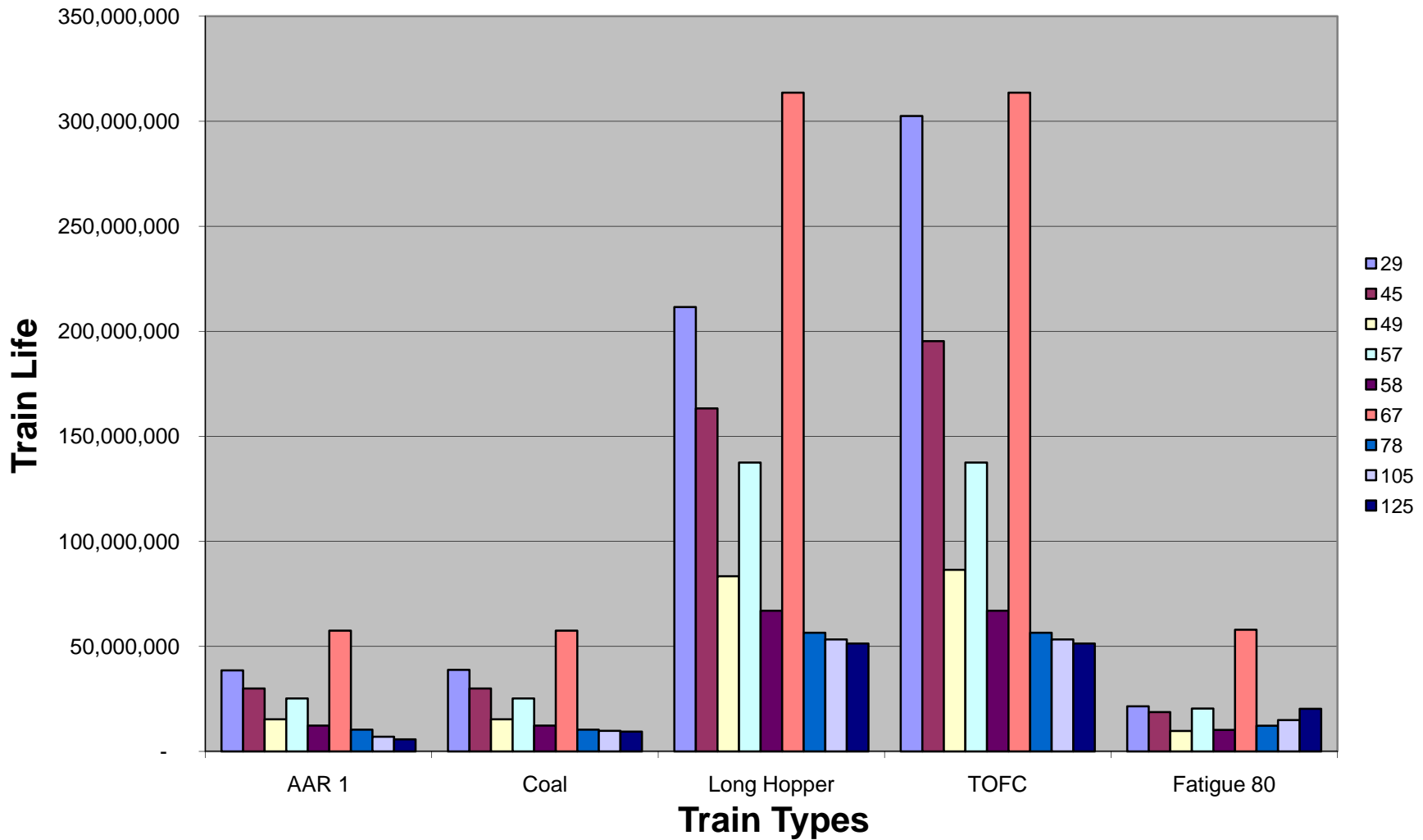
# Train Comparisons

- F80 100 railcars
- AAR 1 3 locomotives, 60 railcars
- Coal 3 locomotives, 150 railcars
- Long Hpr 3 locomotives, 60 railcars
- TOFC 3 locomotives, 100 railcars

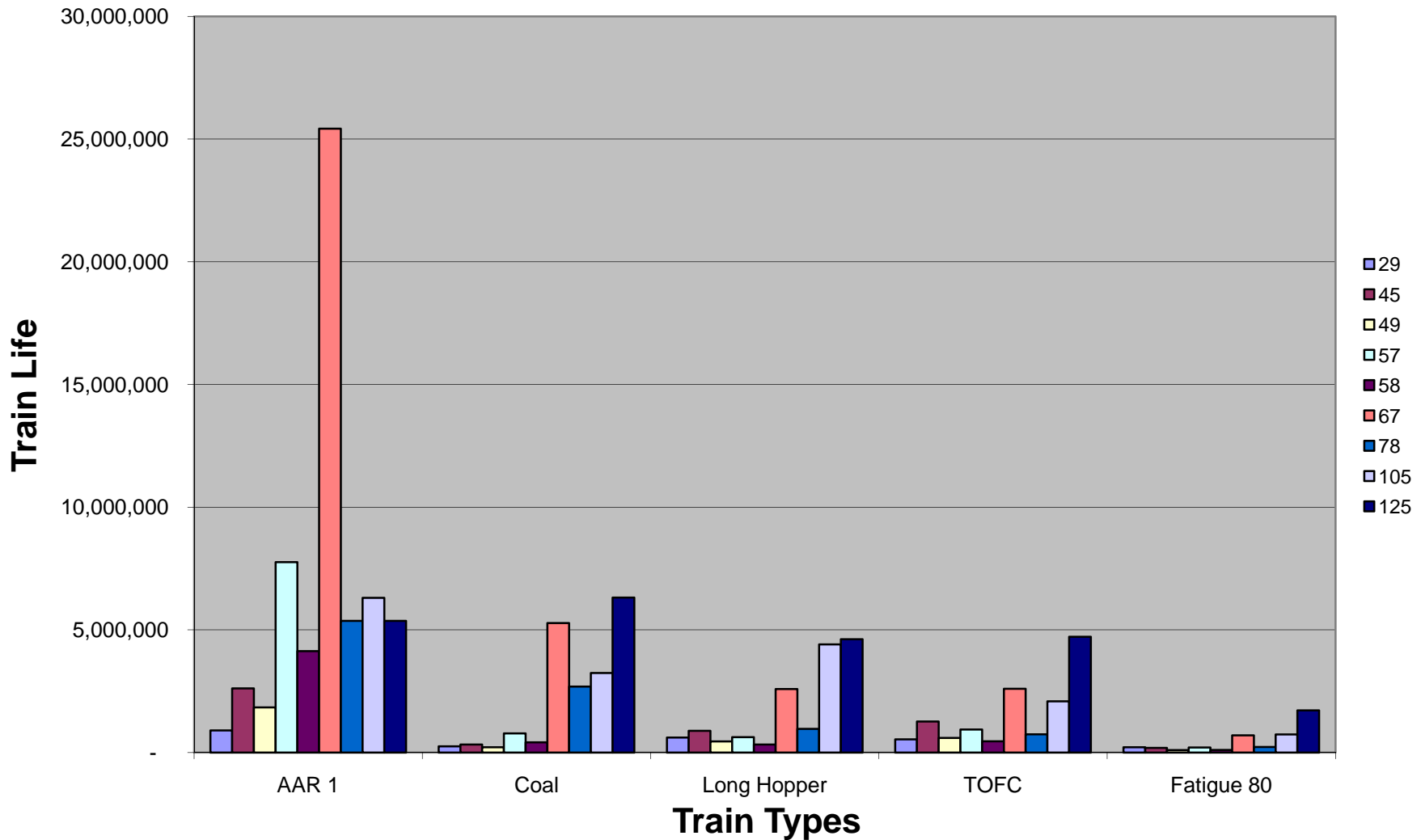
# Check for Train Life

- Check both Maximum Moment and RMC Moment for Maximum and Repetitive Cycles
- Span Lengths – 29, 45, 49, 57, 58, 67, 78, 105, and 125 feet
- Fatigue Category D, assume all cycles are damaging

# Train Life – Maximum Moment



# Train Life – RMC Moment



# Conclusions

- The F80 Loading provides a reference loading useful for overall fatigue design
- The loading is useful for trusses and girders
- Provides an envelope for fatigue design
- Provides a reference for fatigue rating.

# Future Steps

- Examine loading against articulated equipment
- Further development for design and rating
  - Design life and cycle assumptions for bridges
  - Detailed ratings for actual bridges

Thank you!

Questions?