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REDUCED-SCALE RAIL CAR FLOOR FIRE TEST SPECIMEN FEASIBILITY STUDY

SUMMARY
An ongoing computational study was conducted to determine the conditions necessary to demonstrate that a reduced-scale rail car floor assembly for fire resistance testing can provide equivalent results when compared to the results obtained from a full-scale assembly as specified in National Fire Protection Association (NFPA) 130, Standard for Fixed Guideway Transit and Passenger Rail Systems 2014. It was found that the full-sized rail car structural response is better represented in a fire resistance test when the floor assembly is supported on the longitudinal ends (along the walls) rather than the transverse ends (along the car ends) as specified in NFPA 130. These new longitudinal support boundary conditions were used to reduce the size of the current test article while still capturing the essential deflection and failure behavior of the rail car floor in the end-use condition.

Simulation results show that a rail car floor assembly with a width of 2.7 m (9 ft.) and a reduced length of 1.17 m (3.8 ft.), which is one-third of the length of the currently specified test article adequately captures the response of the full-scale rail car floor assembly. This reduced scale floor also exhibited similar deflection, plastic strain and maximum shear stress distributions as observed in the full-scale test article with similar boundary conditions. Since the scaling methodology was based on reducing the size of the floor assembly without modifying the thickness of structural members and insulation, it resulted in identical thermal response for both reduced and full-scale assemblies. The developed methodology was successfully applied to a second rail car floor design and was evaluated through fire resistance tests on both full and reduced scale rail car floor assemblies (Kapahi, et al., 2018).

BACKGROUND
The Federal Railroad Administration (FRA) contracted with Jensen Hughes (JH) to conduct research on the feasibility of reducing the size of the test article for floor fire resistance testing. Rail car assemblies manufactured in the United States are currently required to demonstrate (per Title 49 Code of Federal Regulations Part 238) their fire resistance rating which includes structural integrity and limited heat transmission according to ASTM International, ASTM E119 and NFPA 130. According to NFPA 130, the current test requirement is to use a floor assembly test article that is 3.6 m (12 ft.) long and as wide as a rail car (approximately 3 m [10 ft.]). The test article is simply supported along the transverse ends and has an applied total distributed load comprised of live loads (e.g., passenger crush load), dead loads (e.g., equipment, other articles), and other relevant design loads. The NFPA 130 test limits the fire rating determination using the following three parameters:

1. Transmission of heat through the assembly shall not be sufficient to raise the temperature on its unexposed surface more than 139 °C (250 °F) average and 181 °C (325 °F) at a single point.
2. The assembly shall not permit the passage of flame or gases hot enough to ignite cotton waste on the unexposed surface of the assembly.
3. The assembly shall support the representative loading.

These testing requirements and measurements result in an expensive fire resistance compliance process mostly due to the physical size requirement of the test article. Although there is an interest from rail car manufacturers to reduce the physical size of the rail car floor assembly test article for floor fire resistance testing, it is necessary to first establish that a smaller test article can adequately represent the behavior of a full-scale rail car floor assembly.

OBJECTIVE

The objective of this work was to demonstrate the technical feasibility of using a reduced-scale test article for the fire resistance compliance process.

METHODS

ABAQUS, the commercial finite element software, was used to predict the thermo-structural response of floor assemblies subjected to an ASTM E119 furnace fire exposure. A floor assembly (Design 1) was developed based on field surveys of exemplar rail cars. This floor assembly is representative of a rail car floor. The modeled section was 3.4 m (11.2 ft.) long with structural repetitions every 1.1 m (3.6 ft.), and 2.7 m (9 ft.) wide representing the full rail car width. The section consisted of a stainless steel (SS304) structural frame below a SS304/plywood ply-metal composite floor with spun fiberglass blanket insulation of thickness 76 mm (~ 3 inch) as shown in Figure 1.

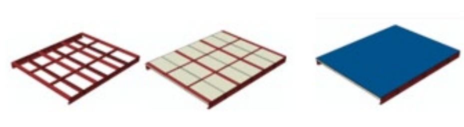

Figure 1. ABAQUS model showing component geometry of Design 1

An alternative assembly design, Design 2, based on a different type of structural support configuration which includes a center sill as shown in Figure 2, was also evaluated. This design was provided by a car manufacturer. The ABAQUS model was 3.7 m (12 ft.) long and 3.1 m (10 ft.) wide with transverse Z channels and longitudinal hat channels. The section consisted of a stainless steel (SS304) structural frame below a phenolic/balsa wood core composite floor with spun fiberglass blanket insulation of thickness 100 mm (~ 4 inch) as shown in Figure 2.

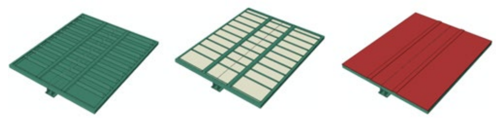

Figure 2. ABAQUS model showing component geometry of Design 2

Thermo-structural analysis was conducted on both designs to understand the full-scale behavior as well as to identify options for dimensioning the reduced size rail car floor. The underside of the simulated specimen was exposed to an ASTM E119 furnace exposure with convective and radiative boundary conditions. An ambient temperature boundary condition was applied to the unexposed side. The uniformly distributed load for Design 1 was 3.6 kN/m^2 (75 lb/ft^2) while Design 2 had a load of 2.4 kN/m^2 (50 lb/ft^2) representing the crush load passenger density and the dead weight of items specific to the individual floor design. Additionally, the weights of the structural frame and composite floor were included in the analysis.

RESULTS

The full-size rail car floor assembly (Design 1 construction) along with the upper frame (not shown) was supported at the transverse ends which represented the rail car trucks. The deflection of the top surface of the model is shown in Figure 3. The figure also shows the transverse edges, which are simply supported with zero deflection, and the longitudinal edges with small deflections (0.01 m to 0.02 m) due to the presence of the side sill and upper frame adding resistance to bending. A representative section with the Design 1 dimensions taken from the center of the full-sized rail car model, shown in Figure 3, indicates the local behavior where the bending stress and deflection are maximum (i.e., approximately 0.08 m). The local deflection behavior for the full-sized rail car floor (Figure 3) compared with the full-scale rail car floor specimens subjected to the two different boundary conditions described above in Figure 4.

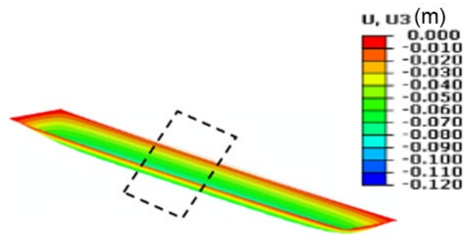

Figure 3. Vertical displacement contours (of the top sheet of full rail car floor

The results show that the full-scale test specimen supported at its longitudinal ends captures the behavior of the full-sized rail car floor with higher deflections at the transverse ends and zero deflection at the longitudinal ends. However, the test specimen supported at its transverse ends as required by NFPA 130 does not capture the full-sized rail car floor behavior.

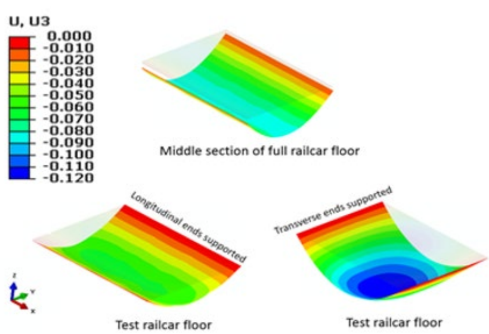

Figure 4. Vertical displacement (m) of the top sheet of full-sized rail car floor (top), full-scale rail car floor supported on longitudinal ends (left) and full-scale rail car floor supported on transverse ends (right)

Reducing the size of the test article for fire resistance testing using the longitudinal support boundary conditions was investigated using a test article with the dimensions equal to the current test article width (2.7 m [9 ft.]) and a length one-third that of the current test article (1.17 m [3.8 ft.]). This reduced scale test article exhibited similar deflection, plastic strain distribution and maximum shear stress distribution as observed in the current full-scale test article with similar boundary conditions as shown in Figure 5.

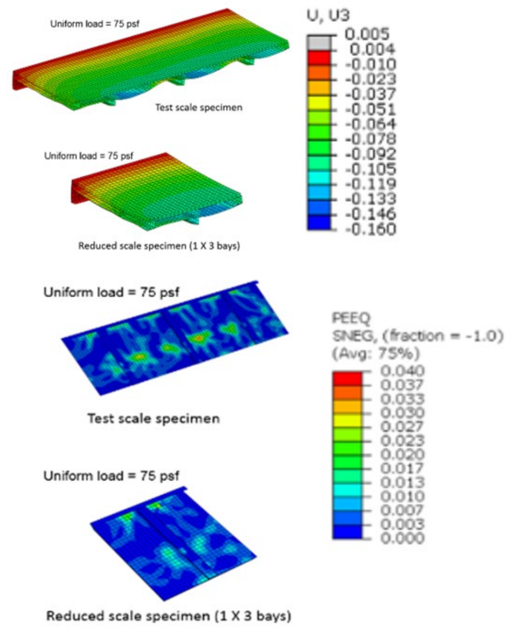

Figure 5. Vertical displacement (top) (m) and equivalent plastic strain (bottom) of the full-scale specimen and reduced scale specimens

The methodology was also applied to thermo-structural analysis of Design 2 for both full-scale (~ 12 ft. long) and reduced-scale (~ 3.6 ft. long) test articles, supported on the longitudinal edges. The distribution of displacement contours depicted in Figure 6, shows that the reduced-scale assembly captures the overall behavior of the full-scale test article.

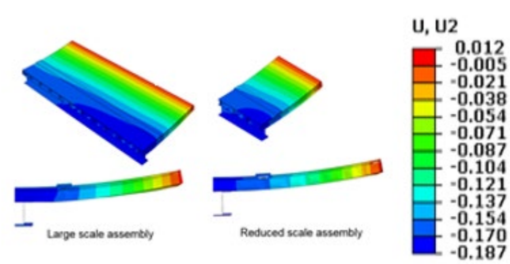

Figure 6. Vertical displacement (m) of the full and reduced scale assembly for Design 2

CONCLUSIONS

This work investigated the feasibility of reducing the size of the rail car floor assembly for fire resistance tests. Results from computer simulations of floor fire resistance tests show that the full-sized assembly response is like that of the full-scale fire resistance test article supported longitudinally, instead of the transverse ends as required in NFPA 130. Using the longitudinal end support boundary conditions, it was shown that the overall behavior of the full-scale test article for fire resistance testing (12 ft. long and full width) can be successfully represented by a reduced scale (4 ft. long and full width) test article.

FUTURE ACTION

It is recommended that a variety of tests of reduced scale floor assemblies be conducted to demonstrate that the scaling methodology can be extended to other rail car floor assembly designs. In addition to reduced scale tests, further research should be performed to investigate insulation models and material models at elevated temperatures to refine the thermo-structural models as well as to better understand the fire resistance tests conducted at Southwest Research Institute.

REFERENCES

ASTM E119-16A: Standard Test Methods for Fire Tests of Building Construction and Materials. ASTM International. https://doi.org/10.1520/E0119-16A

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