Effect of Power Pack Unit on Modular Trailer Spine Beam Deflection

Manish Arya, Pratik Chakraborty, and Munish Dhawan

Abstract For Modularization projects in Oil and Gas industry, Transportation of Structures (i.e. Modules or Pipe Racks) through modular trailers is usually considered as an important activity. Two types of modular trailers, Self-Propelled Modular Trailer (SPMT) and Propelled Modular Trailers (PMT) are used for this purpose. As a part of structural analysis, Trailer deflections and stability are also checked. Excessive deflection of trailer can have adverse impact on transportation operation including effect on structural integrity and/or trailer stability. Power Pack Units (PPU) are considered as essential component of the trailers which provide motion and suspension power to SPMT and PMT. Typically those units are cantilevered from one end or both ends of trailer. Generally consideration of power pack weight in analysis results in lesser deflection of trailer, as effect of those load counteracts to the sagging deflection profile of the trailer. So in general, it is considered that exclusion of the power pack loads will yield conservative result. This chapter discusses how the weight of PPU can generate high trailer deflection and describes viable solution for reduction of such deflection and thus obtaining a favorable trailer profile necessary for safe modular transportation per given project parameters.

Keywords Deflection · Modularization · Power pack · Trailer spine beam

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1 Introduction

SPMTs or PMTs are often used to transport heavy and large objects such as heavy process structures, pipe racks etc. It is important to create optimum and required stability to ensure quality, safety, and reliability in these kinds of transportations. Generally the responsibility of stability during transportation of structures rests with logistics service provider as they analyze all the technical measurement required to achieve the stability. However, structural analysis also must be made before handing the structure to Logistics Service Provider to ensure no failure of structural members and serviceability of structure and SPMT/PMT during transportation.

The stability and effective distribution of imposed load from structure are achieved through hydraulic grouping of combination of trailers and hydraulic suspension of axles. In normal operation, generally two methodologies named three points loading and four points loading are adapted to create stability. In these methods, loads are distributed among different trailer group based on their positions with respect to Center of Gravity (COG) of structure.

The trailers are connected through hydraulic circuits to form into trailer groups, which support the structure. The axles/tires in each trailer groups are assumed to have equal pressure within that trailer group and the total structure weight is distributed as per the individual trailer group COG position in relation to the structure COG.

To analyze the trailer behavior, SPMT trailers are modeled as spine beams in structural analysis software (STAAD Pro). Structure/modules are placed on top of SPMT (spine beams) and the loads/reactions from SPMTs are transferred at the bottom of structure. Under heavy loading of the structures, the spine beams assume a sagging profile. On the other hand, when power pack loads are applied in analysis at the ends of spine beams, those loads create hogging effect on the spine beams and thus reduce the sagging deflection at central span.

For light weighted structure it has been found that sagging deflection of spine beam due to structure load alone is getting converted to hogging profile after application of PPU weight. On some case the magnitude of hogging deflection has been found to be higher than the allowable limit, thus proving analysis with PPU weight consideration as more onerous case. It was found that weights of lighter structures are sometimes insufficient to counteract the moment generated by the application of PPU loads at the cantilever ends of spine beam.

Two possible alternative methods for reducing the trailer deflection are Ballasting and Trailer wheel disengagement. For Ballasting, heavy surcharge load is placed on central span of trailer, which helps in counteracting the end hogging moments. For trailer wheel disengagement method, different set of wheel axles are made off-contact to ground.

Similarly, it was found that the PPU loading is also having impact on the strength parameters (Unity ratios) of pipe rack members. This chapter discusses the trailer wheel disengagement method along with two sample case studies to demonstrate the effect of PPU loading on spine beam deflection and pipe rack members. The effect of trailer wheel disengagement method on above parameters has also been studied.

2 Analysis of Trailer and Deflected Profile—Effect of PPU Load

Sample comparative study is performed for 2 different pipe rack structures. One pipe rack is a continuous braced structure and other is a discontinuous braced pipe bridge. Spine beam deflected shapes for both structures are presented to illustrate the effect of PPU weight on trailer spine beam deflection. For large length of transportation route, two PPUs are used many times. So, as more stringent case, weights of 2-PPUs are considered here. Structure and trailer spine beams are modeled and analyzed to get deflected shape of trailer spine beam.

2.1 Example 1: Continuous Braced Structure (Pipe Rack)

Length of rack = 60 m; Width of rack = 8 m; Height of structure = 10.455 m.

COG in longitudinal direction = 30.011 m.

COG in transverse direction = 4.585 m.

Weight of structure (including steel, pipe, cable trays) = 248 metric ton (Figs. 1, 2, and 3).

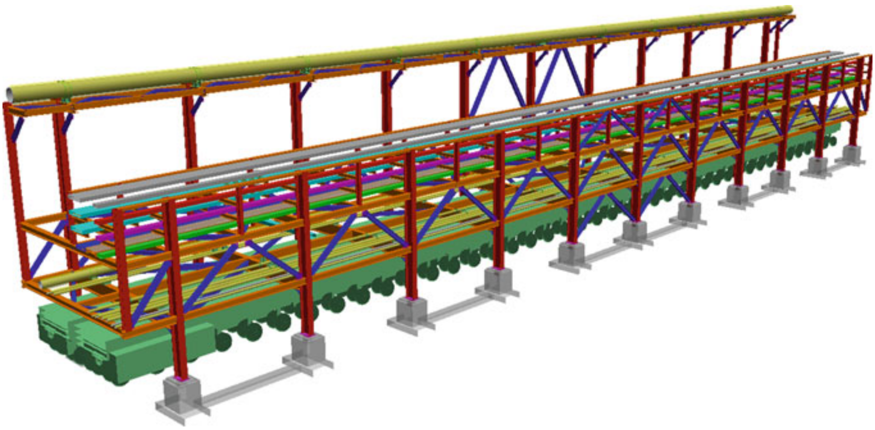


Fig. 1 3D view of example-1 pipe rack

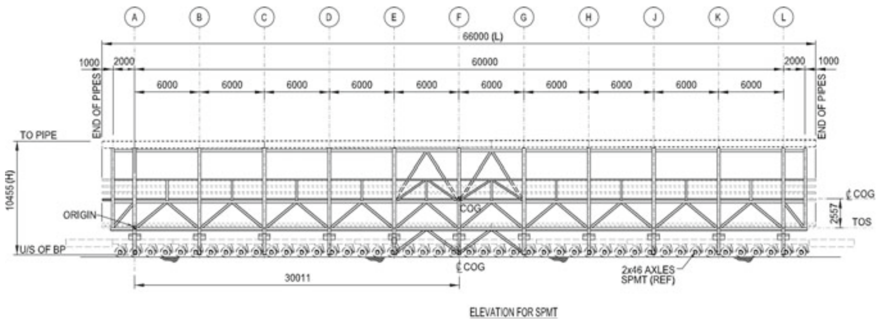
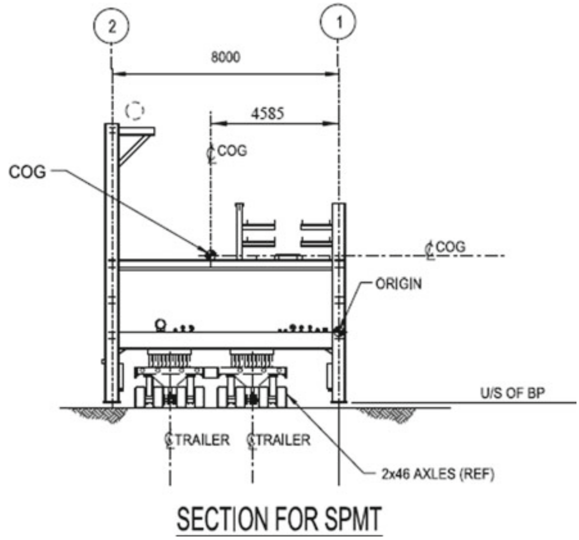


Fig. 2 Longitudinal section of example-1 pipe rack

Fig. 3 Transverse section of example-1 pipe rack



2.2 Example 2: Discontinuous Braced Structure (Pipe Bridge)

Length of rack = 60 m; Width of Rack = 8 m; Height of structure = 12.217 m.

COG in longitudinal direction = 29.794 m.

COG in transverse direction = 3.825 m.

Weight of structure (including steel, pipe, cable trays) = 317 metric ton (Figs. 4, 5, and 6).

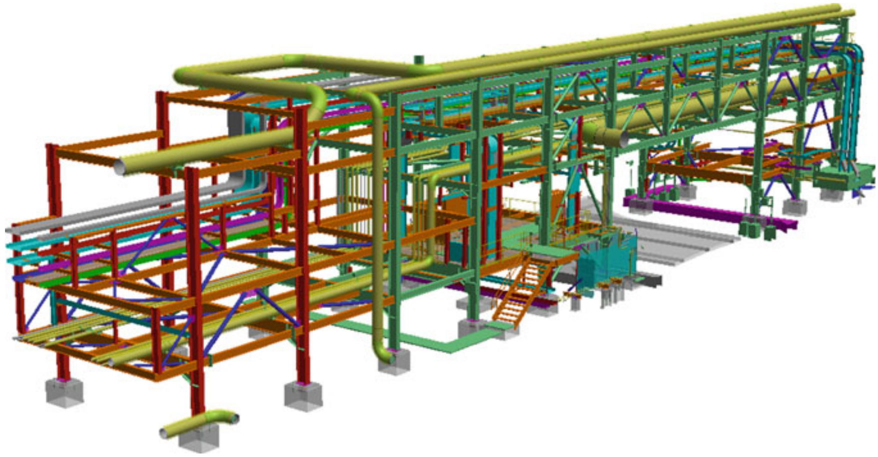


Fig. 4 3D view of example-2 pipe bridge

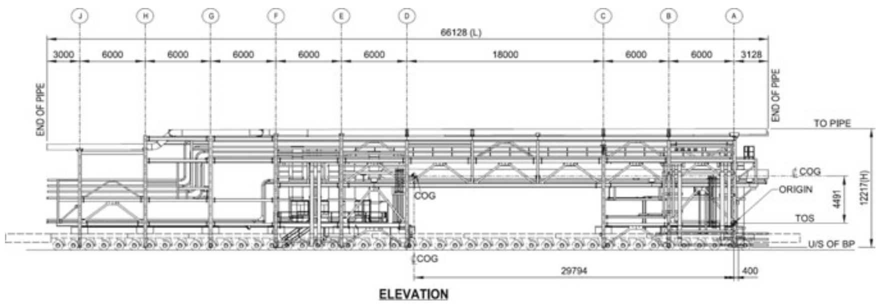


Fig. 5 Longitudinal section of example-2 pipe bridge

3 Modular Trailer and PPU Details

KAMAG K25H SPMT;

Numbers of axles = 46; Longitudinal grouping of axles;

Center to center distance between 2 trailers = 3.3 m in transverse direction;

Spacing of axles = 1.5 m in longitudinal direction;

2 PPU weight = 20 metric ton (Fig. 7).

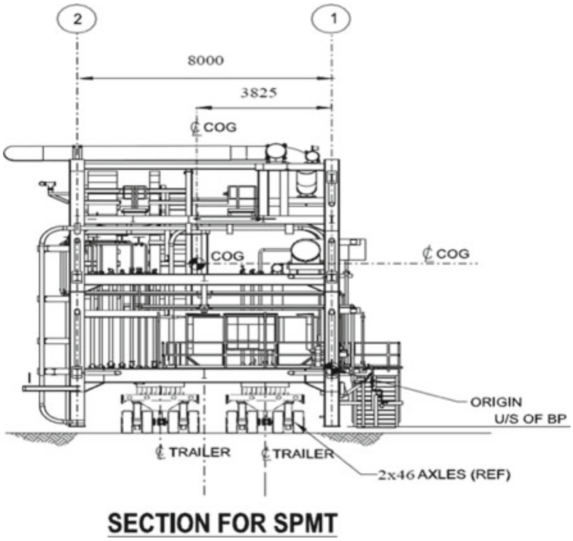


Fig. 6 Transverse section of example-2 pipe bridge

Fig. 7 Picture of modular trailer with double PPU

4 Analysis Approach

To analyze pipe rack and pipe bridge, two type of analysis are performed.

First Analysis—In this analysis, both Pipe Rack (Example-1) and Pipe Bridge (Example-2) are analyzed to calculate the SPMT spine beam deflection with all wheel engaged, without PPU and with PPU condition.

Table 1 Two distinct trailer axles-disengagement profiles

Example 1 (pipe rack)	Example 2 (pipe bridge)
Case (i): 11 + 6D + 3 + 6D + 3 + 6D + 11	Case (i): 21 + 4D + 21
Case (ii): 9 + 6D + 6 + 4D + 4 + 6D + 11	Case (ii): 11 + 4D + 6 + 4D + 6 + 4D + 11

Where "*n*D" denotes "*n*" number of wheel disengaged

Before development of software analysis model, the wheel reactions for each trailer groups are determined by using equation of static equilibrium. When all axles are engaged (i.e. in contact with the ground), the reaction gets generated at each tire. These reactions are kept uniform within particular trailer group (through hydraulic circuit) but differ between each group. Accordingly, the calculated tire reactions for each group have been manually applied as upward uniformly distributed force i.e. UDL (owing to the closely spaced tires). Pseudo supports are modeled in software to make a valid model and it has been ensured that those supports do not attract any reaction.

PPUs get connected to the end of spine beam as cantilever elements. For double PPU case, an adapter is used to connect the PPUs together and then the adapter is attached to the trailer along with the PPUs. To simulate that, a concentrated load equal to the PPU and the adapter weight is applied at the end of spine beam along with a concentrated moment to cater for the cantilever nature of the PPUs. Second Analysis—To control the SPMT spine beam deflection for "with PPU" condition, few wheel axles are disengaged. Weight of disengaged axles, which are not in contact with ground, counteract the moment generated due to PPU weights and at the same time the disengaged axles result into local omission of reaction values. Both of these effects help in increasing the sagging behavior and reducing hogging profile.

To simulate the axle disengagement in software model, reactions have been recalculated considering lesser number of axles for applicable trailer groups and then the upward UDL loads have been omitted at the location of the disengaged axles.

Multiple iterations of disengagement of axles are performed to obtain most favorable deflection profile. Pipe Rack and Pipe Bridge are analyzed with 2 distinct trailer axles-disengagement profiles given in Table 1.

4.1 Result of First Analysis

Sagging deflected profile occurred in spine beam when PPU weight is not applied. This sagging profile changes to hogging profile when PPU weights are applied at the cantilever end of spine beam (Figs. 8, 9, 10, and 11). Significant change in trailer spine beam local deflection and member unity ratios due to PPU weight are noticed (refer Figs. 9 and 11 for deflection and Fig. 18 for Member URs).

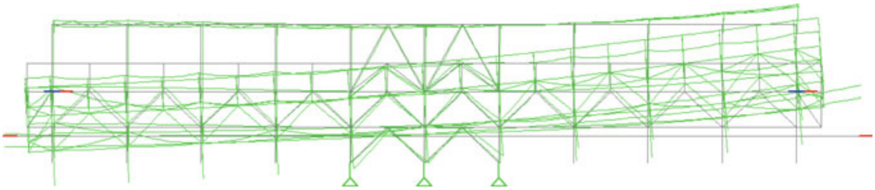


Fig. 8 Example 1 (pipe rack) deflected shape—without PPU weight (local deflection 13.49 mm)

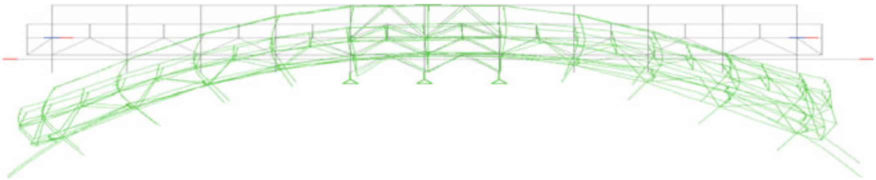


Fig. 9 Example 1 (pipe rack) deflected shape—with PPU weight (local deflection 175.40 mm)

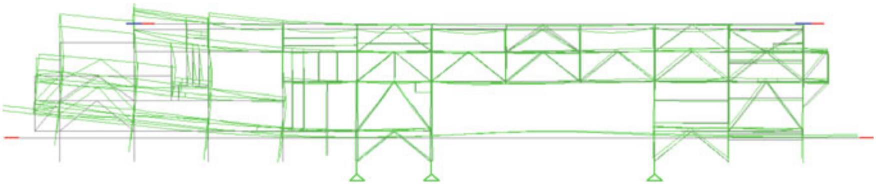


Fig. 10 Example 2 (pipe bridge) deflected shape—without PPU weight (local deflection 60.55 mm)

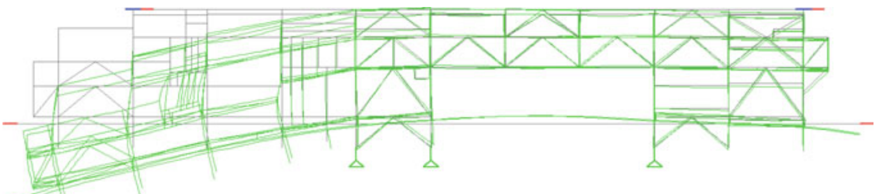


Fig. 11 Example 2 (pipe bridge) deflected shape—with PPU weight (local deflection 252.58 mm)

Generally allowable SPMT spine beam deflection is 100 mm. Hence per above analysis it is clear that we cannot ignore PPU weight while doing the analysis. To bring trailer spine beam deflection under allowable limit, multiple axles of trailer are disengaged and second analysis is performed and results are as below.

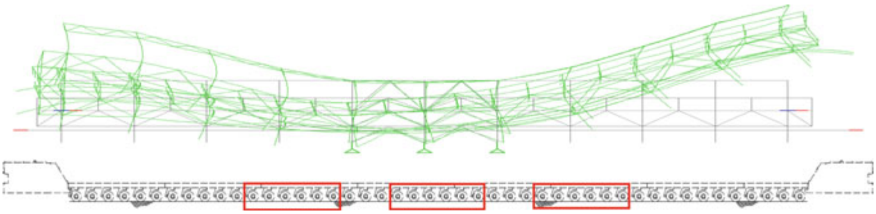


Fig. 12 Case (i) 11 + 6D + 3 + 6D + 3 + 6D + 11 for example 1 (pipe rack) (local deflection 93.87 mm)

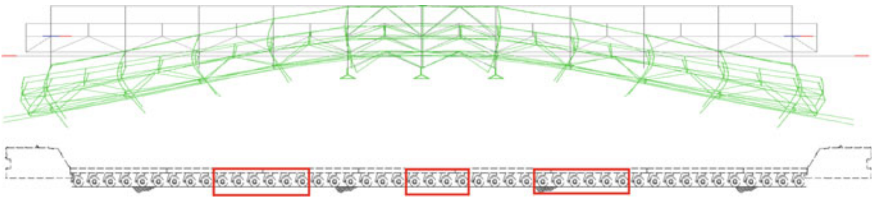


Fig. 13 Case (ii) 9 + 6D + 6 + 4D + 4 + 6D + 11 for example 1 (pipe rack) (local deflection 30.78 mm)

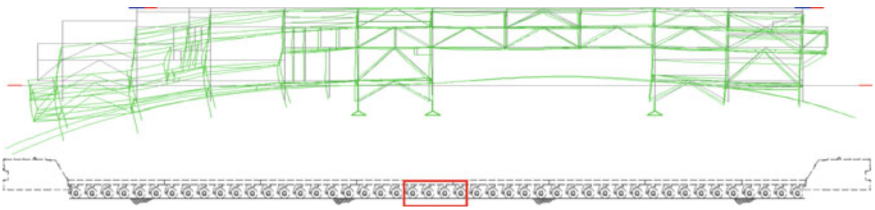


Fig. 14 Case (i) 21 + 4D + 21 for example 2 (pipe bridge) (local deflection 202.67 mm)

4.2 Result of Second Analysis

Analysis based on 2 distinct trailer axles-disengagement profiles is carried out and outcomes are presented here. Figures 12 and 13 show the deflection diagram of example-1 structure (pipe rack) for both cases. Figures 14 and 15 show the deflection diagram of example-2 structure (Pipe Bridge) for both cases. Figures 18 and 19 show the variation in Member URs.

Below Figs. 16 and 17 show the comparison of trailer's deflection and Figs. 18 and 19 show the variation in member URs with/without PPU weight and with both disengagement profiles.

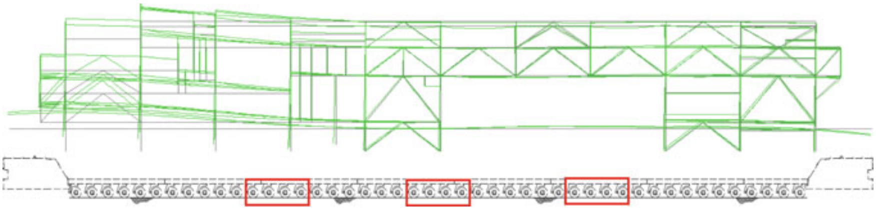


Fig. 15 Case (ii) 11 + 4D + 6 + 4D + 6 + 4D + 11 for example 2 (pipe bridge) (local deflection 31.09 mm)

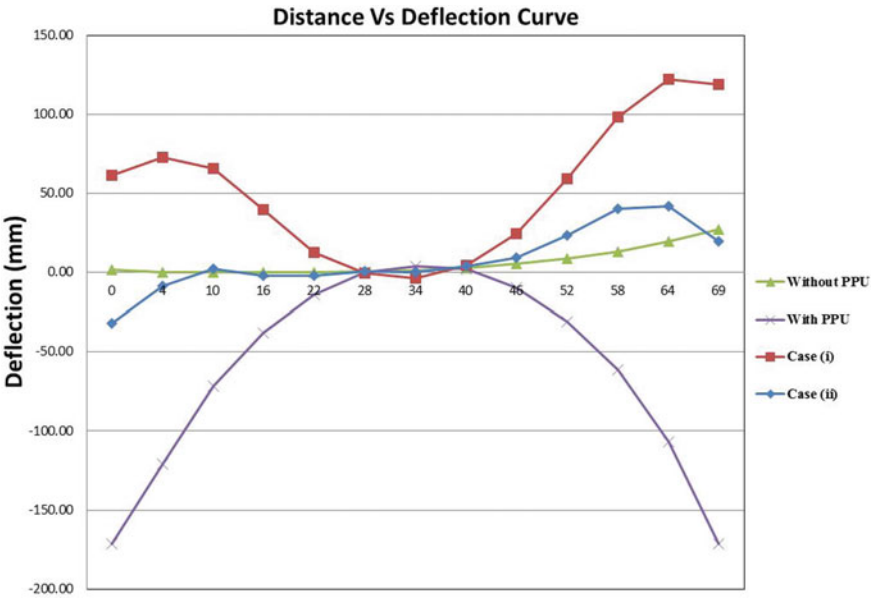


Fig. 16 Trailer spine beam versus deflection curve for axles-disengagement profiles (example 1)

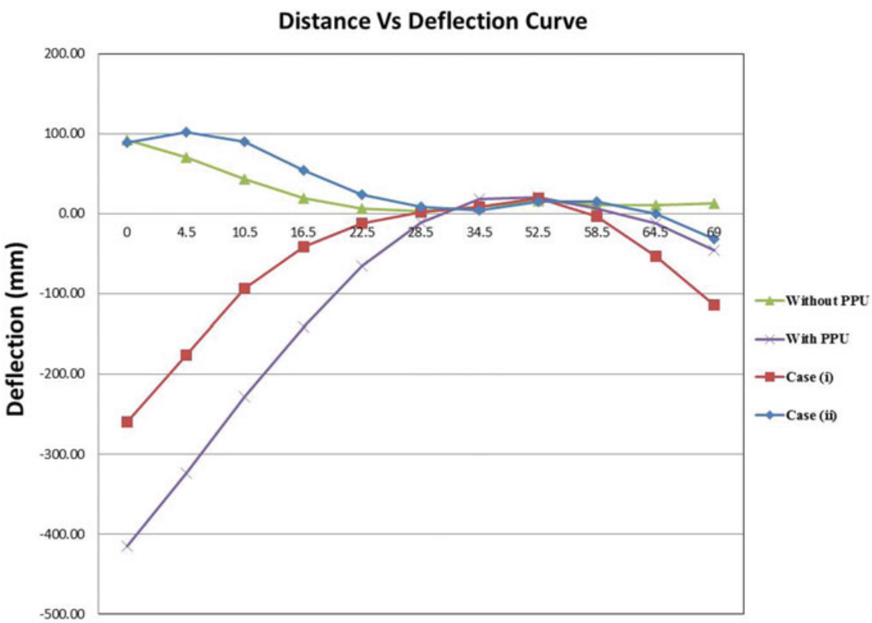


Fig. 17 Trailer spine beam versus deflection curve for axles-disengagement profiles (example 2)

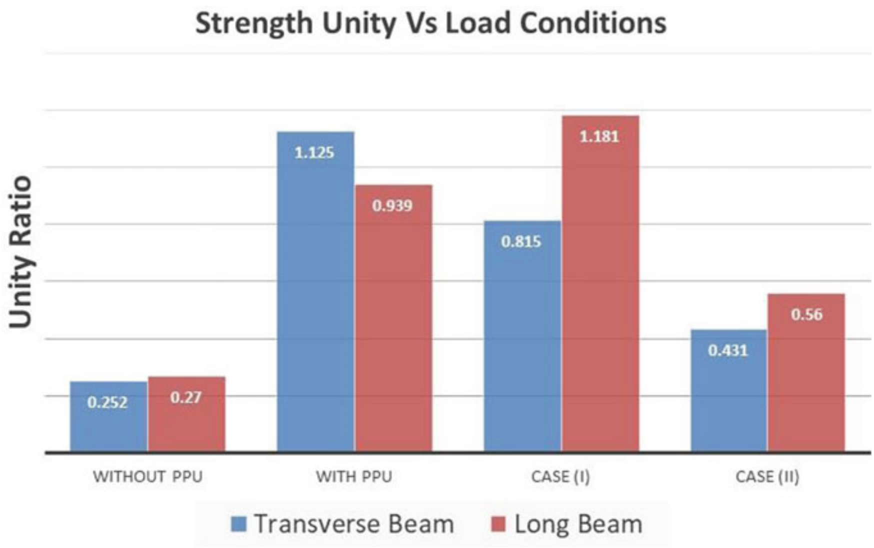


Fig. 18 Variation in member UR (example 1)

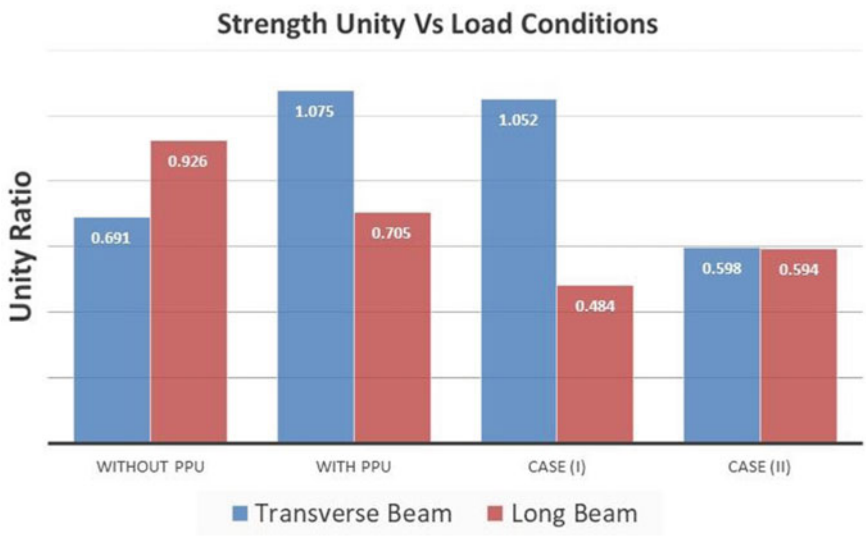


Fig. 19 Variation in member UR (example 2)

5 Conclusion

Figures 16 and 17 curves are based on results of analysis without PPU and with PPU. Results in these figures clearly show that SPMT trailer's deflection with PPU is much higher than without PPU consideration. Deflection of trailer's spine beam varies with different axles-disengagement consideration. Typically each set of disengaged axles yields local sagging effect. Iterative analysis is required to reach at the most optimum trailer profile. In addition to trailer deflection, other aspects like Stability, Member and Connection unity ratios (Strength checks) shall also be looked at with the considered trailer profile. However, it is found that nature of variation in Member URs is generally consistent with that of deflection, i.e. the most favorable trailer profile from serviceability consideration also generally yields toward favorable effect for strength checks.

From the aforesaid case studies, we can safely conclude that PPU weight should not be ignored in land transport analysis. To cater trailer deflection exceedance, method of axles-disengagement can be used in analysis. Disengaged axle profile shall be determined in a way which results into reduction of spine beam deflection.

Having said this, the engineer needs to judiciously apply the recommendations herein to suit particular project requirements, with application of his/her engineering judgment based on project specific consideration. Also, close coordination between Structural Engineer and Logistics Service Provider is required for determination of trailer profile. The final trailer profile shall be mutually agreed upon between both the parties.