

Innovative Structural Concepts for Lightweight Design of Heavy Vehicle Systems

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ABSTRACT

The objective of this paper is to devise innovative lightweight design concepts for heavy vehicle structures. A 1 to 4 prototype of a trailer was built to assess the feasibility of use of polymer composites and to have first hand experience with possible bonding methods to join the design parts. In the current trailer configurations, floor assembly constitutes 70% of the overall weight. The results indicated that sandwich technology with a lightweight core that adds flexural stiffness to the overall design provides a solution to decrease the weight of heavy vehicle systems.

INTRODUCTION

In 14.63 m (48 ft) long haul trailers, the chassis components constitute 73% of its load-free weight, which is about 6,850 kg [1]. The oak floor panels and supporting steel cross I-beams contribute 47% of the structural weight of such trailer hauls. Therefore, Current research efforts on weight reduction of trailers are focused on the structural configuration and materials of floor design [2]. Previous studies showed that the most promising design concepts for reducing the weight of intercity busses utilize sandwich panels of aluminum or fiberglass face sheets and foam cores [3]. Mechanical joining techniques such as bolting and riveting are detrimental to composite material design because of the damage they would cause to the fibers. Fiber reinforced composites undergo weakening and damage when machined or cut which increases the susceptibility to interlaminar shear within the substrate. Therefore, adopting alternative joining methods such as bonding will assist the use of composite material technology into new design concepts [4].

Currently, several truck trailers manufacturers have experimented with and successfully produced sandwich composite technology into their van trailer structures. Martin Marietta Composites has produced a prototype design which implements their *TRANSONITE*® technology which is "a pultruded 3-D, reinforced composite "sandwich" consisting of fiber-reinforced polymer (FRP) laminates and a foam core". Martin Marietta states that *TRANSONITE*® technology is used to provide an alternative for structural and non-structural

flat panel applications while creating lightweight and high strength characteristics [5]. Wabash National Corporation, a designer and producer of vans and intermodal equipment, has implemented composite technology into the sidewalls of the van trailer, focusing on the damage resistance, strength and durability of the lower sidewall trailer sections. The DuraPlate® and Duraplate® HD are designs intended to increase the durability and life of the trailer and also decrease the operating costs [6]. Composite sidewall technology has also been developed by Stoughton Trailers, LLC. Stoughton has developed *Z-Plate*™ which is a "ply-laminate panel manufactured by epoxy coated inner and outer galvanized steel skins" [7]. Although the details of the construction are not specified, the *Z-Plate*™ design can be categorized as a composite sandwich panel with steel face sheets and epoxy core.

As discussed, several attempts have been made to implement composite technology into van trailer systems. These applications have been geared toward the trailer sidewall technology; however, any alterations to the flooring systems of current van trailer designs are obscure or have not been documented. The purpose of this paper is to provide ideas, designs, and analysis for initiating the technology to enhance weight saving and fuel efficiency of freight vehicle systems and apply the

ALTERNATIVE FLOOR DESIGNS

The current floor design configuration of van trailers system comprises 35-mm thick oak floor panels resting on cross I-beams evenly distributed at 0.305 m (1 ft) spacing along the central section of the van, whereas the other set consists of I-beams with overhanging cantilevers over the suspension rail as illustrated in Figure 1. This indicates that the floor assembly has a great potential for weight saving through integrated material-structural analysis.

The baseline loading scenario assumed for integrated structural design of the floor components consists of structural dead loads and the live load applied by a moving loaded forklift, whose weight is assumed to be 11 kN (2,500 lb) per wheel, where the wheels are spaced at 1.0 m.

Alternative design concepts for the structural floor of van trailer were devised in order to reduce its weight

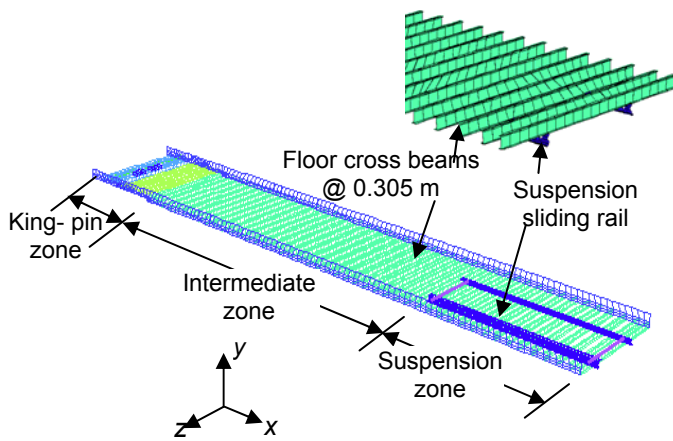


Figure 1 Floor Cross Beams.

below that of the current baseline configuration. All these lightweight designs relied on sandwich panels with various material and geometric characteristics of the core. The main design objective utilized in this comparative study was chosen to be an optimal tradeoff between the overall weight and stiffness of the floor. The following design criteria had to be met by all the alternative configurations considered here.

- The factor of safety in flexure should not be lower than 2.0.

The maximum deflection of a cross beam in an alternative, lightweight floor should not exceed that calculated for a similar steel beam currently used in the baseline floor configuration. In each design alternative, a simple mechanics of material approach was initially used to estimate the required size of the cross-beams, then the analysis was further refined using the 3D finite element Package ADINA [8]. The full span of the floor was modeled along with its major structural members such as cross-members and stiffeners. All cross-beam members of the floor were represented by using 4-node quadrilateral shell elements. Other major parts of the floor, namely the stiffeners, bogie I-beams and sidewalls were all represented by using beam elements. The finite element model developed for the four different design configurations are shown in Figure 1. The mesh sizes were adjusted in such a way that most of the nodes were common to two or more surfaces, thus reducing the need for contact elements. The maximum size of the quad element was normally maintained at 15 cm. This approach resulted in models consisting of about 5,000 elements, on average. The top covering layer of the floor is made of oak wood (Modulus of Elasticity, $E = 11$ GPa and Poisson's ratio, $\nu = 0.3$) and is represented using shell elements whose thickness is assumed to be equal to be 35 mm.

The boundary conditions of the models were formulated by assuming that the trailer was in stationary condition. The floor was constrained in the vertical, Z, direction at points where it rests on the landing gear and the bogie. Nodes corresponding to these locations were identified first, followed by applying the constraints directly on these nodes. Four concentrated loads representing the

four wheels of the forklift were calculated by assuming that each wheel carries a load of 11 kN. The position of the concentrated loads is assumed to be at the center of the floor span, where the deflection is expected to be the highest. The structural behavior of each floor design configuration was determined and evaluated as summarized in Table 2.

ALTERNATIVE 1 - The core of the floor consists of I-cross beams that are 0.305 m (1 ft) apart as illustrated in Figure 2 and made of various materials. For each alternative material selection for the I-cross beams, Table 1 specifies the minimum standard dimensions required for the I-beam cross-section to satisfy the design criteria outlined above. In addition, Table 1 displays the factor of safety, the maximum deflection, and the weight of the unit floor area corresponding to every material option for the I-beams.

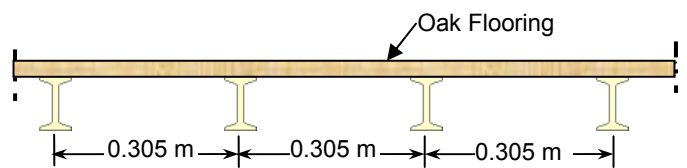


Figure 2 I-Cross Beam Floor

The results presented in Table 1 reveal that the current weight of a baseline van floor can be reduced by as much as 69 or 66 percent when the steel I-cross beams are replaced, through an integrated design approach, by I cross-beams made of carbon-carbon composite or magnesium alloy, respectively.

These results demonstrate the drastic structural weight reduction in heavy vehicles that can be achieved through rational application of lightweight materials that integrate the layout and geometric design with the material selection process. This conclusion is further supported by similar studies on three other alternative design concepts for the trailer floor.

ALTERNATIVE 2 - Sandwich panel consisting of top and bottom fiberglass faceplates and a core formed of transverse C-channel cross beams, as shown in Figure 3.

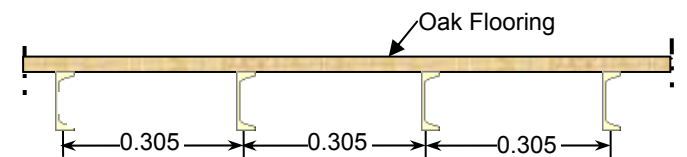


Figure 3 C-Channel Beam Floor.

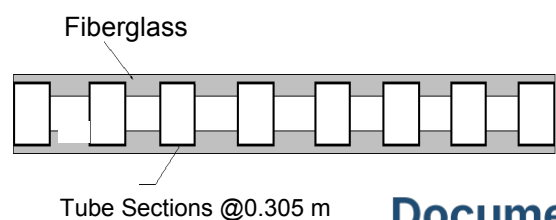


Figure 4 Tube Floor

Documents

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