DEVELOPMENT OF COMPUTER BASED PROCEDURE FOR QUANTITATIVE EVALUATION OF BUS SUPERSTRUCTURE IN TYPE APPROVAL

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Abstract

This paper deals with development of a computer simulation procedure, as a substitute for physical rollover test, to evaluate bus body structure crashworthiness. It is expected that, when completed, this procedure can be proposed to the authority to enhance its current type approval procedure related to crashworthiness which is merely based on qualitative and empirical field experiences without performing real rollover test. This procedure will enable a firmer base for judging the crashworthiness of bus structure.

The proposed computer simulation procedure is being developed based on ECE R66 which allows partial bus body structure to be physically tested. In this case, sections of bus super structure built up from at least two bays are used to represent the whole structure. A finite element method computer program capable of dealing with elastic plastic calculation is employed to calculate deflection of a bay structure under incremental quasi-static loading until residual space limit is reached.

From the obtained force-deflection curve, the strain energy absorption capacity of the structure will be evaluated if it is large enough to absorb potential energy resulting from rollover test. A bus body superstructure sample from a representative domestic bus manufacturer is used as test cases.

***Keywords**: ECE R66, bus superstructure, rollover test, FEA, quasi-static incremental loading, elastic plastic*

1. Introduction

Buses play a very significant role in short and long distance mass transport in Indonesia. Long distance transportation by buses is still a very competitive transportation alternative, despite the availability of other modes of transportation such as trains and airlines which offer advantages such as comfort and shorter travel time. Its role becomes much more dominant for economical reasons especially for commuting in the area when other transportation modes area unavailable. The ever increasing role of transportation by buses is due to the fact that the development of high ways seems to be a more affordable priority as compared to development of other infrastructure such as railroad.

The authority, with regard to the ever increasing bus transportation role, tries to continuously improve regulation concerning bus design rule in order to enhance safety of the passenger, based on collected field experience. So far the regulation improvement that can be easily obeyed by the manufacturers is related with features and devices that can be visually inspected. Unfortunately, there is not much can be done when it deals with features related to structure crashworthiness. As a matter of fact, in the existing bus type approval, the evaluation method for superstructure crashworthiness is merely based on empirical field experience. There is no quantitative measure such as calculation or test on the superstructure strength required to fulfil the type approval.

This condition is understandable since the appropriate technique for evaluating structure crashworthiness generally is costly, especially when physical structural testing is required. Low bus production volume as depicted in Tab. 1 may not justify the use of such method economically. Hence, a more economical technique, possibly based on computer simulation, need to be sought. This idea was triggered by findings of many investigators that have successfully utilized computer simulation to evaluate bus superstructure crashworthiness [2, 3]. Most of them carried out their work by using LS DYNA, a computer program that capable of simulating crash phenomenon.

Tab. 1. Number of bus production [1]

Bus Gross Weight	2005	2006	2007	2008	2009
5 – 10 tons	1235	831	889	1788	1038
10 – 24 tons	1194	423	787	1168	1290

The preliminary work described in this paper aims to develop a simulation method that does not require massive computing power. The method is based on ECE R66 which allows testing of bus superstructure sections using quasi static load approach for determining energy absorption capacity of bus superstructure in rollover. Furthermore, to obtain a more affordable technique, a finite element method capable of dealing with elastic plastic calculation is employed to determine deformation of test structure under incremental quasi-static loading until residual space limit is reached. Then the energy absorbing capacity of the structure can be evaluated through load deflection curve.

2. Bus body manufacturing

There are major bus coach manufacturers in Indonesia that have long history with good reputation. Even though they have been growing from simple metal fabrication shops their role in providing bus fleet in the country is undeniable. Many good looking city buses as well as inter city buses produced by them can be easily seen at any time on the street. Their way of manufacturing bus coach basically are the same even though their facilities may vary.

Most buses and coaches in Indonesia are constructed on chassis frame supplied by authorized distributors. Typically a chassis frame for large bus (10 tons and higher) is equipped with rear engine, manual transmission, rear wheel drive, mechanical spring suspension, and other standard equipments including braking system, steering, and fuel tank, as shown in Fig. 1 (left). Of course alteration of the specification to a certain extent can be made according to customer request such as automatic transmission and air suspension. Typical wheel base of this type of bus chassis frame is 5.950 m and wheel track of 2.450 m. What left for the bus manufacturers to build are body, electrical chassis, interior and seating.

The illustration described in the following was taken from a major bus coach builder. Generally the work starts with computer drawings of coach exterior, interior, seating lay out and body frame, that are produced according to customer request, typically like the one shown in Fig. 1 (right). A mock up is then built based on the drawings, to facilitate visualization and physical feel on the design, especially when discussing with customers.

Construction work of bus body starts with manufacturing of components from rectangular steel tubes, steel channels and steel sheet. The principal components are then assembled into six main body panels i.e; floor framework, right side wall framework, left side wall framework, roof framework, front end and rear end. Using a body assembling fixture (Fig. 2 left), the floor framework is layed firmly on the fixture and followed by other five body panels which are then welded together to form a superstructure (Fig. 2 right). Welded joints connecting the six body frameworks are made carefully to obtain required strength and rigidity. A completed body frame is then mounted over a designated chassis frame and fastened using bolted joints that are prepared according to chassis manufacturer recommendation. Bracings and stringers are then attached, and followed by steel sheet skin installement. Most welding jobs are done using arc welding. From this point, further works are related to seating, interior and exterior finishing.

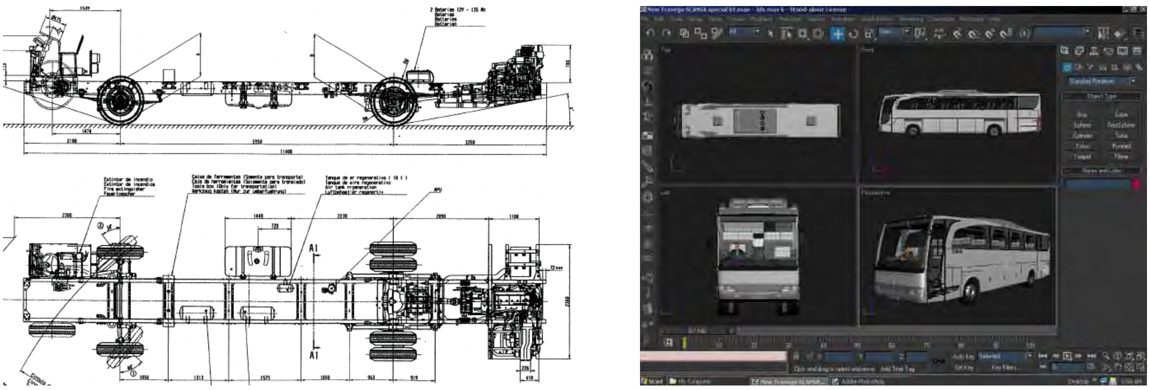

Fig. 1. Typical bus chassis frame available from authorized distributor(left) and drawings of bus exterior (right)

3. Existing type approval procedure

Before being manufactured every new bus design has to go through type approval as administered by Directorate of Road Traffic and Transport, Ministry of Transportation, Indonesia. The term new design may not relate to new design of super structure. It is rather related to dimension, geometry and appearance of the bus. In type approval bus manufacturers need to submit documents that specify main vehicle dimensions, engine capacity, fuel, transmission system, brake system, lighting system and reflectors. Essential drawings to be included are front view, side views, rear view and seating layout, exploded view, longitudinal cross section, door details and electrical diagram.

All documents are scrutinized until the issuance of approval (to built) letter. The manufactured vehicle will be physically checked its conformity with approved document, followed by a series of tests such as braking test, emission test, head lamp test, horn test, side slip test, turning radius test, vehicle dimension, vehicle weight, running test, structural inspection (visually), auxiliary completeness, and performance. If everything conforms to the approved documents then type approval letter is issued by Provincial Department of Road Traffic and Transport.

Fig. 2. A body assembling fixture (left) and a completed bus superstructure (right)

An important issue to be raised here is that there is no procedure in the type approval that deals with superstructure crashworthiness evaluation. Approval on this aspect is merely based on empirical field experiences. There is no quantitative tool to guide the authorized officials in carrying out this important job. At the most factory visits are performed by the authority during manufacturing of the vehicle.

4. Development of computer based method

4.1. Physical model

There are a number of methods to evaluate superstructure crashworthiness as recommended by ECE R66. A particular method used as reference in this study is quasi-static loading test of body sections as an equivalent approval method. In this method body sections is physically tested on a loading machine where incremental quasi-static load is applied to obtain its corresponding load deflection curve.

In this study the possibility of using computer simulation as substitute for physical quasi-static loading test is investigated. As generally faced in computer simulation, the validity between results and physical behaviour of body section structure is critical. Therefore, the formulation of the computer model is commenced by thoroughly investigating the physic of the structure.

Figure 3 shows computer drawing representing bus superstructure under investigation, which physically shown in Fig. 2 right. This particular drawing was reconstructed from 2D drawings obtained from manufacturer, which were not part of documents submitted for type approval. The way the structure is built can be visualized by looking at Fig. 4 and 5. Floor framework (Fig. 4 left), body side frameworks (Fig. 4 right) and roof framework (Fig. 5 left) are welded together to form superstructure (Fig. 5 right). So, the body frames as the primary structures for protecting passenger during rollover are built at the final stage of superstructure construction. The body frames as basic structures are not constructed at the beginning of construction such that the weld joints can be made freely without restriction. Consequently weld joints connecting pillars and roof cross member may not be very perfect. This fact needs to be taken into account in the computer model. A body frame consists of right and left pillars, and roof cross member (roof bow), manufactured from rectangular steel tubes of 80 mm x 60 mm, 28 mm thickness. Figure 6 shows joint between pillar and roof bow, partly interfaced by cant rail. During manufacturing pillars and roof cross member (roof bows) are curved by using hydraulic press machine in order to meet desired shape of bus body. Longitudinal side wall members are welded to the pillars. In this aspect strain hardening due to pressing and local weakening due to weld joint (at heat affected zone) need to be taken into account in the modelling.

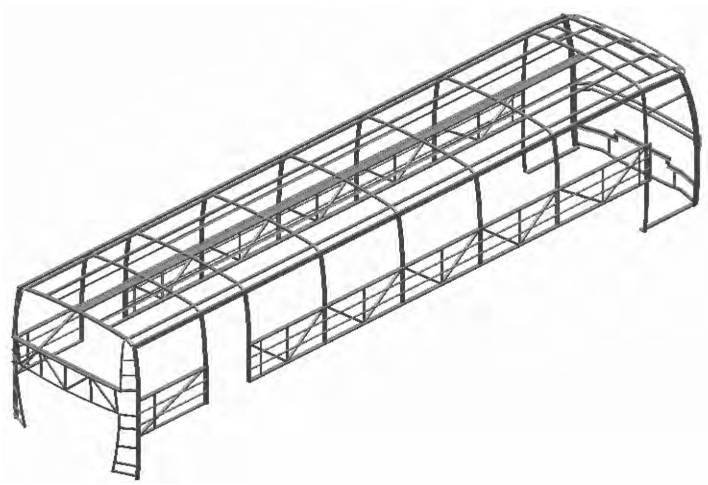

Fig. 3. Computer drawing of bus superstructure (floor framework not shown)

Fig. 4. Floor frame (left) and body side frame (right)

Fig. 5. A roof framework (left) and a completed superstructure (right)

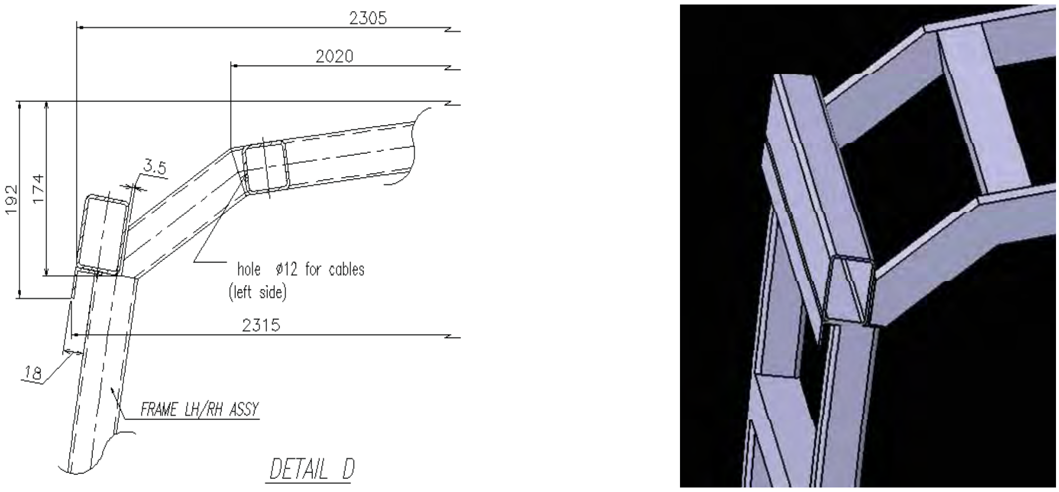

Fig. 6. Details of joint between pillar and roof bow

4.2. Preliminary Results

In this paper, a body section that includes door and emergency exit is chosen as an example. It is assumed that this particular section is the weakest among other sections due to door openings. Figure 7 left shows finite element model of superstructure section representing two bays. It was observed that the floor framework, for the case under investigation, is much heavier than the side wall framework. Therefore, the bottom ends of pillars were assumed to be restrained against translation and rotation in all directions. A similar analysis involving floor framework is still in progress. Geometrical details of the structure were represented as accurate as possible in the model, however, simplification of member cross sections were made while maintaining their area moment of inertia to have simple finite element mesh that was not prone to error. In the finite element simulation this structure were subjected to a quasi-static load applied at the contrail as shown in Fig. 7 right, where $\alpha = 90 - \arcsin(800/H_c)$, with H_c= 3305 mm.

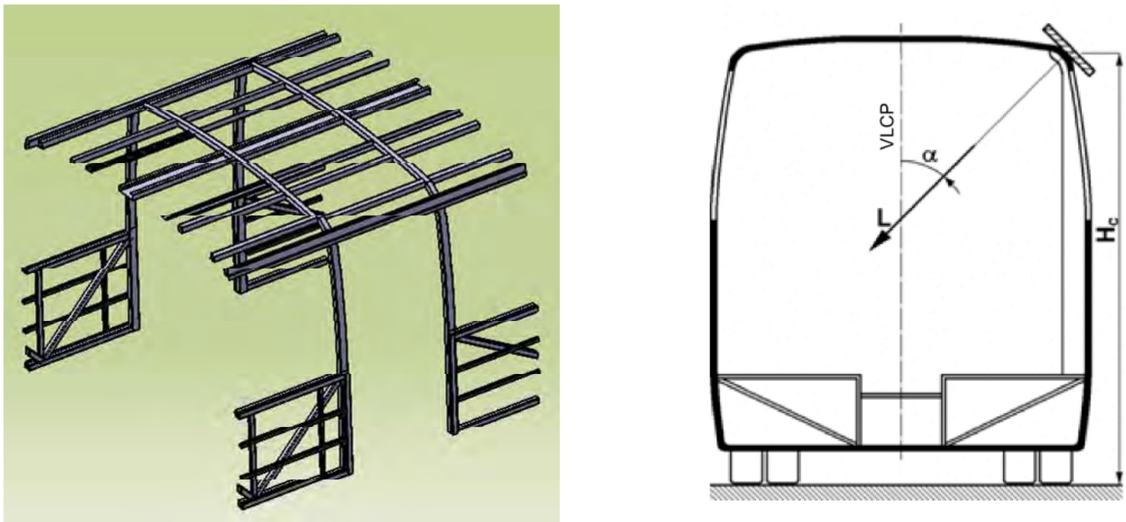

Fig. 7. Geometric model of a section of superstructure (left) and direction of quasi static load (right)

For simulating elastic plastic behaviour of a body section under quasi static load, bi-linear material models representing steel structural member property in elastic plastic region were used. A model as shown in Fig. 8 left with yield strength of 255 MPa and ultimate strength of 402 MPa was utilized to represent material for pillars and roof bows. Weakening due to welding process and strain hardening due to pressing were not being taken into account in this simulation. Analysis of microstructure and mechanical property of heat affected zone and strain hardening to predict mechanical properties of the material are needed.

Figure 8 right shows the result of FEA simulation superimposed with residual space limit taking into account overhead luggage compartment. It can be seen that the deformation of right pillars just reached the residual space limit. To match the deformed structure obtained from FEA and residual space limit trial and error procedure was used.

The resulting load vs. deformation curve is represented in Fig. 9 left, while its associated energy vs. deformation curve is shown in Fig. 9 right. Dots shown on the graphs represent increasing loads exerted on the structure. The most right dot corresponds to the load when plastic deformation of the structure just reached the residual space limit. From load vs. deformation curve obtained from finite element analysis, then the energy absorbing capacity of the superstructure section was determined to be 22430 Joule.

Total energy to be absorbed by superstructure during a rollover test can be calculated as $E_T = 0.75Mg\Delta h$, where M is unladen kerb mass of the vehicle, g is gravity and Δh is the vertical movement of vehicle centre of gravity during a rollover test. Using vehicle data as follows: M = 10,250 kg and $\Delta h = 2.738 - 1.499 = 1.239$ meters then total energy can be calculated as $E_T = (0.75)(10250\text{ kg})(9.81\text{ m/sec}^2)(1.239\text{ m}) = 93438$ Joule.

Rollover energy to be absorbed by a body section can be calculated based on a formula given by ECE R66 as $E_i = E\,(m_i / M)$, where E_i is energy to be absorbed by the i^{th} bay and m_i is mass of the i^{th} bay. The necessary data to determine the mass m_i were not available at this moment. Therefore the term (m_i / M) was modified to be the ratio of associated mass of the i^{th} bay as part of the superstructure to the total mass of the superstructure. Using this approach, then the energy to be absorbed by defined superstructure section under investigation was determined to be 16298 Joule.

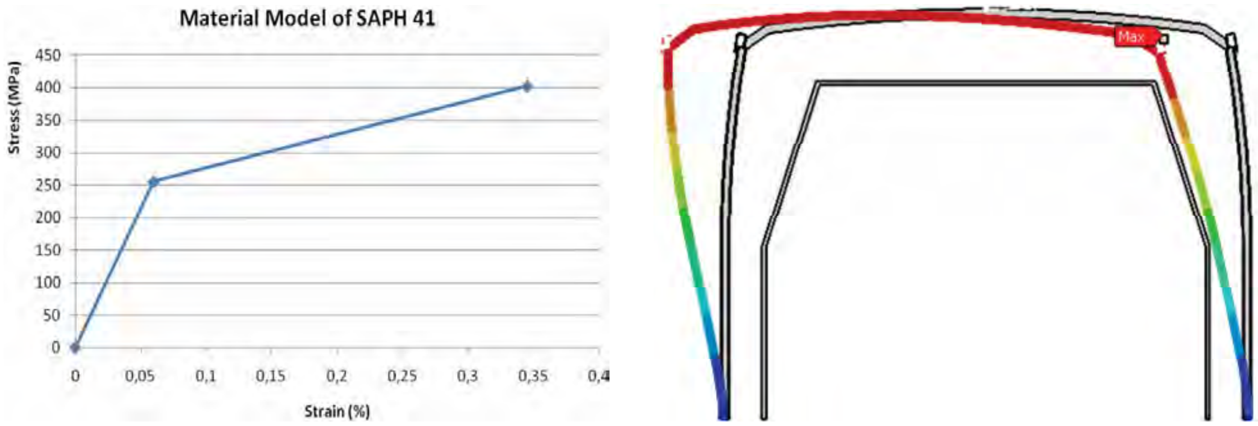

Fig. 8. Material model (left) and plastic deformation of finite element model of body section (right)

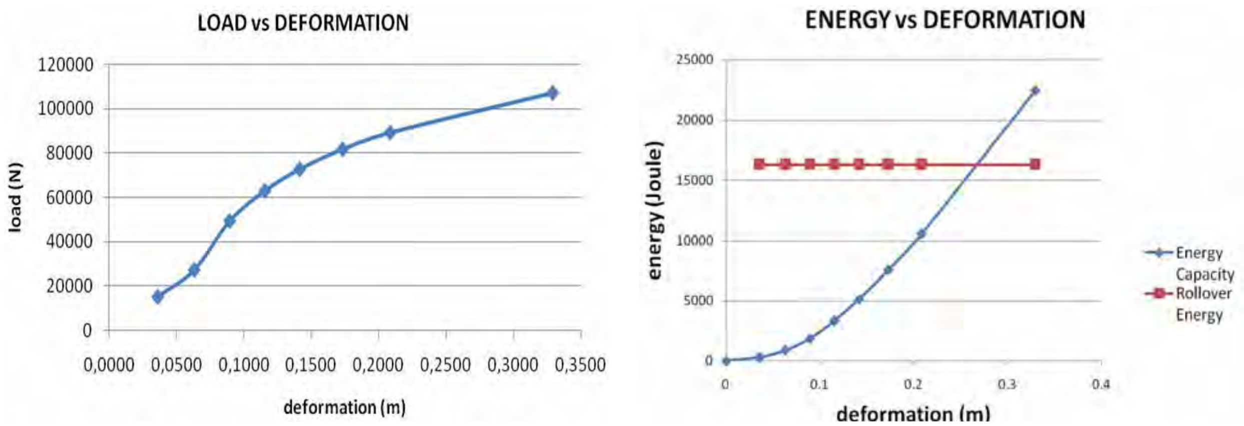

Fig. 9. Load vs. deformation (left) and energy vs. deformation (right)

Figure 9 right shows an example of energy absorbing capacity of a superstructure section which is, in this case, numerically proved to be higher than the rollover energy. It should be noted that imperfections were not considered in the FEA model, so this particular finding can be regarded as too optimistic.

5. Closure

Preliminary study on computer based procedure for quantitative assessment of bus superstructure crashworthiness has been carried out. Further investigation is still going on to make the procedure appropriate to be practically applied in type approval. One important aspect is improving the accuracy of the FEA model by taking into account change of material properties due to welding and manufacturing processes, as well as imperfection of weld joints. Fine tuning the FEA model with experimental works is also of importance.

Based on experiences encountered during data gathering, there are preparation steps need to be done if the authority seeks for enhanced crashworthiness evaluation of bus superstructure such as a computer based approach, as the followings.

a) Drawings submitted for type approval need to include position of bus CG, detailed drawings of superstructure, material properties used for superstructure, detail of welded joints especially on the structure critical in rollover, and detail of interior necessary to define residual space
b) Fostering personnel in the Road Worthiness Division of Ministry of Transportation with appropriate competency in vehicle structural analysis and related computer simulation should be prioritized.

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