13th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2009, Hammamet, Tunisia, 16-21 October 2009

MODERN TOOLS MAKE REVERSE ENGINEERING EASIER

Zoran Lulić, Petar Ilinčić, Goran Šagi
University of Zagreb
Faculty of Mechanical Engineering and Naval Architecture
Ivana Lučića 5, 10000 Zagreb, Croatia

ABSTRACT

The paper presents the usage of the optical measuring system and computer aided design in the process of converting a city bus into a panoramic bus. The conversion goal is to enable easier transfer of tourists and city sightseeing. This intervention requires the removal of the solid roof from the vehicle body structure and the addition of two security frames (roll bars). Such a modified bus must meet certain regulations regarding the public transportation and passengers' safety in the event of the bus rollover. The modified body structure and security frames must be strong enough to withstand the static load equal to the maximum allowable total mass of the vehicle. Based on body structure strength regulations, CAD and FEM models were created. A strength analysis of the modified body structure showed that stresses in such a construction would not exceed the allowed stress for a given material. In addition to the FEM body structure analysis, the calculation of the roll bar stability was made, resulting in a conclusion that no stability loss could occur and that the security frames or body structure will not fracture.
Keywords: optical measuring, body structure modification, CAD & FEM model

1. INTRODUCTION

The paper describes a realistic modification procedure of a city bus into a panoramic bus, with special attention paid to optical measuring methods of the vehicle body structure and to the analysis of stress and deformation of the reconstructed vehicle body structure for the requested load case.
Due to the lack of the original technical documentation related to the city bus body structure, which served as a basis for the modification into a panoramic bus, dimensions and shapes of the vehicle body structure were measured by the TRITOP non-contact optical measuring system. Thanks to the optical measuring method and digitalization process, a high-quality computer wire-frame model was made, which was a good basis for the further construction development and FEM analysis of stresses and deformations. As there are no regulations for this bus category, and as there are panoramic buses without any security elements on the EU market, a load case of modified bus is determined in agreement with Croatian vehicle technical inspection authorities.

2. OPTICAL MEASUREMENT SYSTEMS

TRITOP system is a mobile high-precision optical measuring system which determines the 3D position of markers and other visible elements on the surface of a measuring object and enables fast and efficient on-site measurements. TRITOP system consists of a professional photogrammetric digital camera, a portable computer, scale bars, and coded and uncoded reference points. When measuring, the photogrammetric camera captures high resolution pictures of the measuring object and relevant object points are identified through markers, adapters or labels. The TRITOP software process captures photos, calculates the 3D coordinates of markers and adapters and displays them as a cloud of points. These points are used for the creation of a CAD wire-frame model which is a basis for the FEM stress and deformation analysis. The system measurement accuracy is 0.02 mm per 1 m of the object size. To measure a complex model, such as a bus structure, it is necessary to create hundreds of photos taken from different angles.

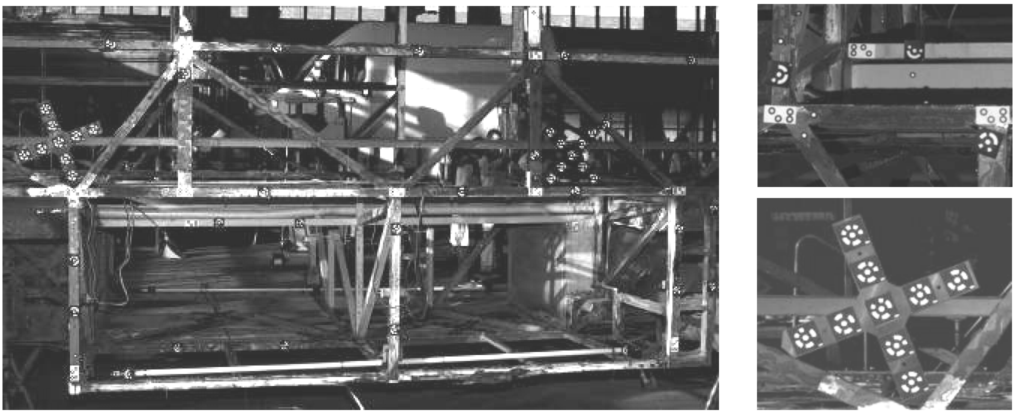

Figure 1. Left: Section of the bus body structure with coded and uncoded reference points, adapters and scale bars (white bar). Right: Detail of uncoded (above) and coded reference points (below).

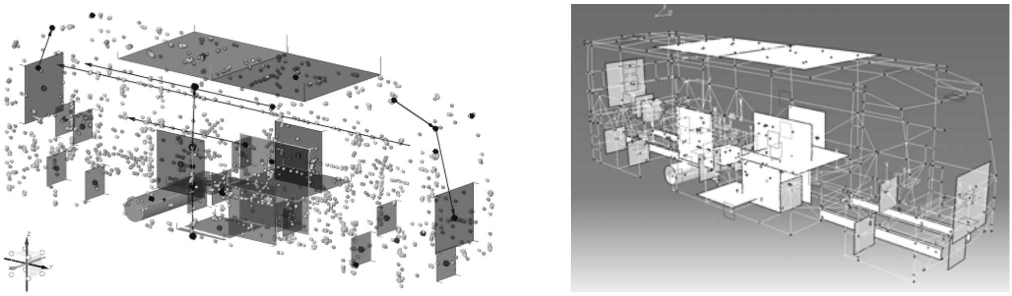

Figure 2. Definition of planes and lines in TRITOP software and a computer wire-frame model

3. BUS BODY STRUCTURE MODIFICATION

The conversion of an original city bus into a panoramic bus required significant modifications of the vehicle body structure. The main feature of a panoramic bus which enables sightseeing is the absence of a solid roof. Losses of the vehicle body structure rigidity, caused by the roof removal, required the strengthening of the body structure in the floor area and in the side section of the bus body structure. Also, a longitudinal rectangular thick-walled profile was added. In addition, the second passenger door was removed and closed with an appropriate stiffening structure. Additional protection of passengers in case of bus rollover was provided by the installation of roll bars at the front and rear part of the vehicle. The main purpose of these roll bars is to ensure the necessary space for the survival of passengers in case of bus rollover.

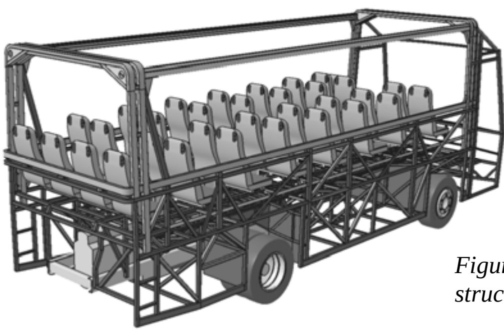

Figure 3. Design of the panoramic bus body structure

The design of a modified body structure is a result of design optimization and FEM calculations. In accordance with laws and regulations on the safety of road motor vehicles, the previously mentioned roll bars and the remaining body structure have to be strong enough to endure static load, which corresponds to the maximum technically permissible mass of the vehicle (weight of empty vehicles and the total weight of passengers). In other words, in case of bus rollover, the body structure and roll bars must ensure the stability of the structure and “safe space” for the passenger survival. On the other hand, such a load case is not very likely to happen since in the actual rollover, dynamic forces must be taken into account and therefore loads may be considerably higher. Because of that, all calculations were made with the safety factor S = 1.5.

4. FEM ANALYSIS MODEL

The strength calculation was made by the finite element method using the appropriate software. Load case and boundary conditions are shown in Figure 4. Load is divided into five groups and consists of concentrated forces and continuous load. The continuous load is coloured orange, and blue arrows indicate the concentrated forces. For the purpose of calculation, the bus model is laid on the ground over the roll bars.

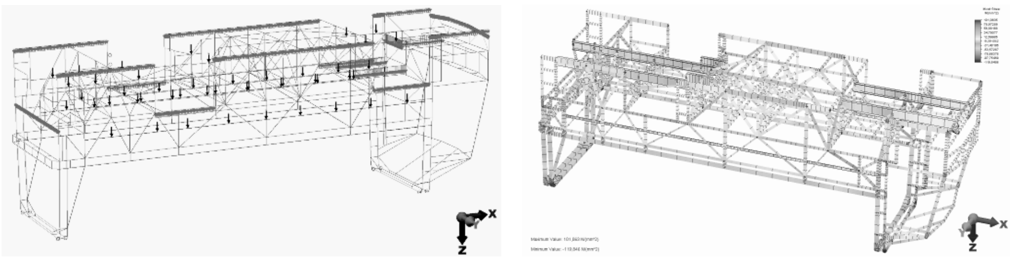

Figure 4. FEM analysis model of the bus body structure and maximum stress values in beam elements

The first load group represents the power train and suspension masses. The second group consists of the load caused by the outer panelling mass and the vehicle interior mass. The third load group are passengers’ masses. The vehicle is intended for the transportation of 36 passengers, where the expected average passenger mass weight is 75 kg. The fourth group is the load of the driver’s weight and the driving mechanism mass. The fifth load group consists of the fuel tank, batteries and other accessories of the vehicle, such as air filter, expansion tank, engine coolant radiator, etc. Load due to the vehicle body structure own weight is simulated within the FEM software.

5. RESULTS

Maximum stress occurs in roll bar elements which are in contact with the ground. Maximum stress value of 120 N/mm^2 in given elements is lower than the adopted maximum allowable stress $\sigma_{allowed}$ = 160 N/mm^2 and considerably lower than the yield stress value $R_{p0,2}$ = 240 N/mm^2.

Maximum stress values which occur in certain parts of the body structure and which are lower that the allowed stress value are partly a consequence of required simplifications in the FEM modelling. In fact, the actual roll bar construction is reinforced with 3 mm thick sheet metal in the upper transverse band, which was not taken into consideration in the FEM analysis. Because of that reinforcement, the stress value in this area should not be taken as critical and the real stress value certainly will be below those obtained by FEM calculation. In addition, stress values in most parts of the body structure are relatively small and far below the allowed values. The largest displacements of the body structure for the applied load case are up to 1/1500 of the total length, which means that the structure can be placed in line with very rigid structures. Displacement of the body structure in the rear suspension area is about 5.7 mm. This displacement value should not be taken as crucial from the stiffness viewpoint because the reinforcement was not modelled in order to simplify the calculations.

Roll bar stability. Since the roll bar construction is relatively slender, in some load cases there is a danger of stability loss and sudden appearance of large deformations, which would endanger the passengers’ safety. For this reason, an additional verification of roll bar stability was required, which was done through two separate calculations. The first one analyzed only the roll bar pillar stability and the second, the whole roll bar. In both cases, elements were loaded by a unit force, and the first Eigen-value is the value of the critical force. A critical force is considered to be a force by which the loss of stability and a rapid pillar buckling occur. For the applied load case, i.e. the unit force multiplied by the buckling load multiplier, the critical force amounts to 43600 N. A roll bar is built of four pillars; therefore, the load acting on one pillar is one fourth of the total load applied to the whole roll bar. Results have shown that buckling will not occur because the load of 26250 N acting on a pillar is lower than the critical load.

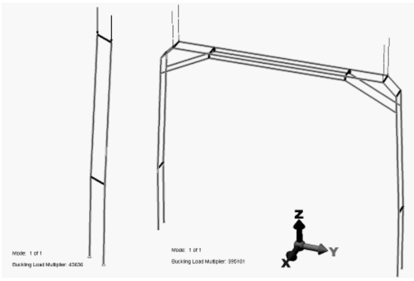

Figure 5. Roll bar stability analysis – a unit force load case

Figure 6. A panoramic bus – final product

In the second part of the roll bar stability analysis, a roll bar was loaded with four forces whose total sum equals 1 N, as shown in Figure 5. In the second case, the critical force amounts to 395101 N. This is approximately nine times higher value than the one in the first case. It means that the loss of stability will occur if the load acting on the roll bar is higher than the critical value of 395101 N.
Values given in the second case are the result of stiffeners in the upper roll bar section. Since the expected load in most unfavourable case is about 55000 N and the critical value is about seven times higher, it can be concluded that the loss of stability will not occur.

6. CONCLUSION

Body structure measurement using the TRITOP system has shown numerous advantages concerning the accuracy and speed of the measuring process, especially with larger objects such as ours. Measurement results in the form of digital "cloud of points" provide the fastest way of obtaining the body structure geometry, which is later used in the design process and FEM analysis. The defined load case used in the FEM analysis includes only static load. In real exploitation, dynamic loads also occur, resulting in a significantly higher real load values. Therefore, all calculations were made with the safety factor S = 1.5. As there are no rules for this bus category and panoramic buses without any security elements are on the market, these calculations are a good compromise.

Acknowledgement
The presented results are obtained during the work on the scientific project "Biofuels – the necessity for sustainable mobility in the Republic of Croatia", which is funded by the Croatian Ministry of Science, Education and Sports.

7. REFERENCES

[1] GOM mgh - http://www.gom.com/
[2] Topomatika d.o.o. - http://www.topomatika.hr/
[3] Bühler, O.-P. A., *Omnibustechnik – Historische Fahrzeuge und aktuelle Technik*, Vieweg & Sohn Verlagsgesellschaft, 2000, ISBN 3-528-03928-0
[4] Pippert, H., *Karosserietechnik – Konstruktion und Berechnung (Omnibus, Lkw, Pkw)*, 3. Aufl. Vogel Buchverlag, 1998, ISBN 3-8023-1725-4
[5] Reimpell, J., Stoll, H., Betzler, J. W., *The automotive chassis: Engineering principles*, *second edition*, Butterworth-Heinemann, 2001, ISBN 0-7506-5054-0
[6] Reimpell, J., *Fahrwerktechnik: Federung und Fahrwerkmechanik*, *2. Aufl*., Vogel-Buchverlag, 1983, ISBN 3-8023-0513-2