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DESIGN AND STATIC STRESS ANALYSIS OF ELEVATOR CAR SUSPENSION DURING OPERATION

Yusuf Aytaç Onur
Zonguldak Karaelmas University, Faculty of Eng. Mech.Eng. Department, 67100 Zonguldak, Turkey

C.Erdem Imrak
ITU, Faculty of Mech. Eng. Mech.Eng. Department Gumussuyu, 34437 Istanbul, Turkey

ABSTRACT
This paper introduces analytical and numerical approaches for elevator car suspension. Numerical analyses are performed by finite element method, dividing 3D car suspension model into mesh of 7 mm, 10 mm and 15 mm element sizes. Two different methods are used for analytical calculations. The first method is simplified one and used by safety calculations of current elevator installations, and the second one is more sophisticated and more detailed than the former one. It involves inner moments occurred at the corner of frame and load distribution on bottom member of car suspension. In order to compare the stress results from these analyses, an illustrative example of elevator car suspension is given.
Keywords: elevator car suspension, finite element method, safety calculation

1. INTRODUCTION
The efficient vertical handling of passengers is vital to elevator engineering. In addition to raw materials, this operation provides a continuous flow of parts and assemblies through the workplace and ensure that materials are available when needed [1]. Elevator car suspension safety calculations are extremely important since elevator car suspension handles person besides such materials. All the parts of elevator installation should be designed adequately and be safe for safe operation of an elevator [2].

It is extremely hard to predict location of passengers entered to the car as well as their distributions in normal running condition. Loads imposed on car suspension members are more complex than other elevator equipments since there are various type of loads going into the car. In this case, certain assumptions as regard location and type of loads must have been devised. Car suspension calculation includes the most important knowledge about safety of loads and/or passengers whom in the car and which increases lifetime of car. Car suspension and guiding members must be designed withstand to which loads and moments exposed under whole running conditions [3]. In this study, car suspension structure with bolted joints to be analyzed is discretized to the its members and analytical solutions considering two type of approach in compliance with standards and static stress analysis are performed utilizing finite element method, dividing the car suspension model into mesh of 7 mm, 10 mm and 15 mm element sizes. In order to compare the stress results from analysis, an illustrative example of elevator car suspension is given.

2. ANALYTICAL CALCULATIONS OF CAR SUSPENSION STRUCTURES
Two different approaches are used for calculating the stresses and displacements of elevator car suspension structure. The first approach used for analytical calculations consists of simplified method considering the safety calculations of elevator installation. The second approach is accurate and detailed more than simplified method, and involve inner moments occurred at the corners of

suspension. In the second approach, loads on the platform regard uniformly distributed on the bottom channel and since structure is symmetric and placing of loads as a symmetric to the vertical axes of suspension, inner moments occurred on the overhead beam corners are same values M_1, in the same manner inner moments occurred on the bottom beam corners are same values M_2 as shown in Figure 1. Inner moment, M_1 can be obtained equating angles of distortion for the left end of the crosshead beam and upper end of the upright. In addition M_2 can be obtained equating angles of distortion for the left end of the bottom beam and bottom end of the upright. The following equations represent analytical values M_1 and M_2.

$$M_1 = \frac{F_T L^2}{24} \cdot \frac{6hJ_2J_3 + 9LJ_2^2 - 2hJ_1J_2}{h^2J_1J_3 + 2Lh(J_1J_2 + J_2J_3) + 3L^2J_2^2} \tag{1}$$

$$M_2 = \frac{F_T L^2}{24} \cdot \frac{4hJ_1J_2 + 6LJ_2^2 - 3hJ_2J_3}{h^2J_1J_3 + 2Lh(J_1J_2 + J_2J_3) + 3L^2J_2^2} \tag{2}$$

where: F_T is total load (N), L is length of upper and lower beams (mm), h is length of vertical beam (mm), J_1 is moment of inertia of crosshead beam (cm^4), J_2 is moment of inertia of vertical beam (cm^4), J_3 is moment of inertia of bottom beam (cm^4).

In elevator installation, car dimensions have been occurred according to number of passengers. These specified dimensions have been used for modeling process. In this study, 5 passenger car design is considered for stress and displacement analysis [3].

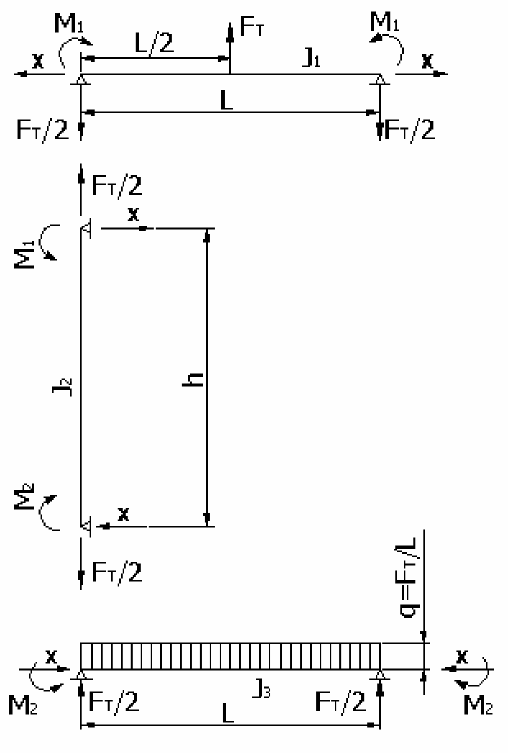

Figure 1. Force and moment distribution on car sling members.

3. MODELING OF ELEVATOR CAR SUSPENSION

The rapid developments in numerical techniques, faster computing ability and greater memory capacity are allowing engineers to create and test industrial equipment in virtual environments. Through finite element analysis these sophisticated simulations provide valuable information for designing and developing new products [4]. The main parts of a car suspension are the crosshead, uprights and the bottom channel.

The crosshead beam must be parallel to the safety plank for no distortion. The crosshead is a pair of structural members, generally channel-shaped, which form the top of the frame. In this study, elevator ropes suspension has been performed by means of hitch plate. The vertical uprights are the vertical structural members at the side of the car. Stiles are U-shaped and L-shaped steel profiles. The safety plank is the structural member similar to the crosshead beam, forming the bottom of the frame and safety plank supports the car platform, on which passengers and/or loads rest during the travel [5].

4. STRESS ANALYSIS WITH DIFFERENT PARAMETERS

An elevator car suspension is designed for 5 passengers with 400 kg capacity (F_y) and 525 kg car weight (F_k). Car suspension model has been formed by bolt connection. All holes of bolts that are found end of the beams have been fixed as boundary conditions and having taken into consideration loads (F_y + F_k) equally imposed on holes of hitch plate of crosshead beams. Car weight equally imposed on car floor connection brace surfaces contacted by car as uniformly distributed load and consideration load with weight of ropes equally imposed in holes of bolt connections. In this study, SOLID187 tetrahedron finite element which is commonly preferred in the structural analysis of solid bodies with 10-nodes, each of 10 nodes of this element has three translational degree of freedom in the nodal x, y, z directions has been used. Three different SOLID187 finite element sizes which are 7 mm, 10 mm and 15 mm have been applied to the solid car suspension body regarding computer memory capability and processing time since the less element sizes the more elements and nodes. Structural steel (Young's Modulus (E) is $2.1\text{x}10^5$ N/mm^2 and Poisson Ratio (ν) is 0.3) has been selected as a beam material [6].
Results from finite element analysis have been depicted separately for each independent beams of car suspension. Changes in the stress values versus considered analytical methods and finite element method at the crosshead, bottom beam and stiles are shown in Figure 3. Changes in the displacement values versus considered analytical methods and finite element method at the crosshead and bottom beam are shown in Figure 4.

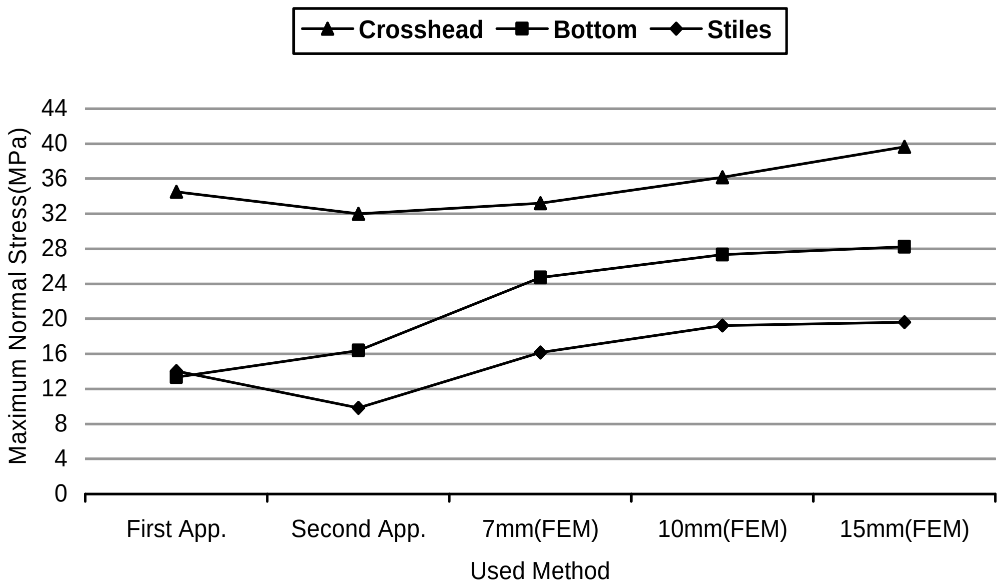

Figure 3. Changes in the stress values versus used method.

In this paper, finite element analysis has been executed for under certain loading and boundary conditions and different finite element sizes for each car suspension members. Figure 3 shows that stress value determined by second analytical approach (32.02 MPa) decrease according to the first analytical approach (34.52 MPa) on crosshead since inner moments which are at the corner side of the beam curtail maximum moment. In addition stress values determined by second analytical approach (16.4 MPa) increase according to the first analytical approach (13.34 MPa) on bottom beam since considering load equally distributed on bottom beam rather than single load and stress value determined by second analytical approach (9.82 MPa) decrease according to the first analytical approach (14.03 MPa) on vertical beam. Instead of these certain loading conditions, for finite element analysis when we regard more accurate loading condition for bottom beam which car weight equally imposed on car floor connection brace surfaces contacted by car as uniformly distributed load [3] and different finite element sizes, stress values virtually increased twice times than analytical solutions in bottom and stiles. When we focus on stress values obtained by finite element analysis in different element sizes, along with the increase of element size, stress values obtained go away from two analytical solution results. Finite element analysis displacement values in different element sizes decrease for all of car suspension members according to analytical solution results.

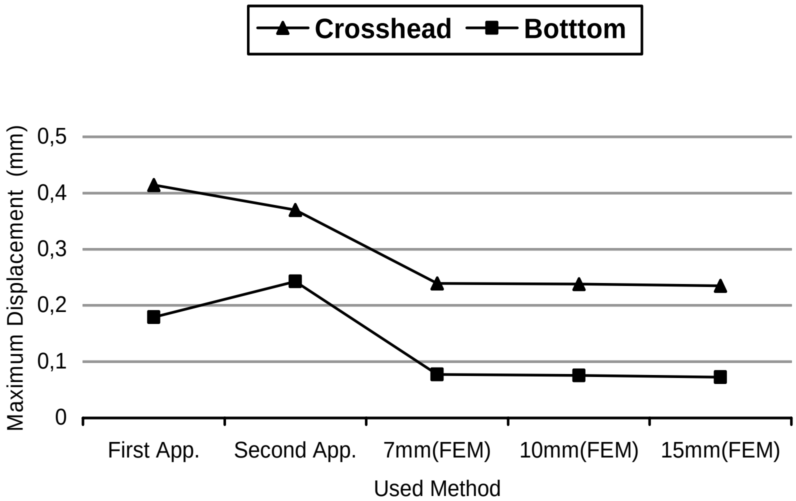

Figure 4. Changes in the displacement values versus used method.

5. CONCLUSION

The design of a car sling system with for 5 passengers with 400 kg capacity and 525 kg car weight and a case study has been investigated. In this study, the stress and displacement analyses of car suspension system have been examined considering as independent simple beams. When looking at the finite element analysis results in various element sizes, results given by 7 mm element size are closer to the analytical calculation results and give more reliable results than 10 mm and 15 mm element sizes. Along with the increase of element size in the constant car suspension continuum, it can be said considering results, finite element method gives rough estimated results. Stress results from finite element method are a highly reliable numerical method if element size should be as small as possible regarding process time spent and memory of computer. Stress values obtained on crosshead and vertical beams are adjacent to the FEA solutions but stress on bottom beam increase virtually twice times than analytical solutions since regarding more accurate loading condition [3]. Determined stress values are quite less than allowable stress value(90 MPa) specified in EN81-1 [7,8].

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