# The Simulation of Seismic Effects on Guide Rail Fasteners and Re-design of Brackets

Abdülmelik Sancak[1], Adem Candaş[2], C. Erdem İmrak[3], Sefa Targıt[4]
*[1,2,3]ITU Elevator Technologies Laboratory, 34437 Istanbul, Turkey*
*[4]ASRAY, Pelitli Yolu Str. No:133 Gebze/Kocaeli, Turkey*

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## ABSTRACT

In public buildings such as hospitals, universities, schools, people and equipment that need to be evacuated after an earthquake can be hardly transported. The brackets that connect and secure the elevator car and counterweight rails to the walls of the concrete elevator shaft are damaged as a result of the seismic waves. Hence, elevators cannot be used because the car and counterweight of the elevator cannot run on the rails. In this study, simulations were conducted to determine the effect of earthquake loads on the bracket parts. Finally, bracket elements were re-designed to withstand earthquake loads to use the elevator after being affected.

## 1 INTRODUCTION

Elevators are important systems that ease daily life by providing transportation of between floors. In public buildings (hospitals, schools, etc.) elevator has an important role. When natural disasters occur such as earthquakes, some elevators are incapable of working after the disaster due to the damage on its structural parts. One of these parts are the brackets that connect and secure the elevator counterweight rails and car rails to the walls of the elevator shaft. Brackets are damaged as a result of the earthquake thus counterweight and car cannot move on the guide rails. The important thing is to evacuate people after the earthquake, but they cannot be evacuated or they are evacuated with difficulty. Based on these situations, the bracket part should be designed or arranged to withstand earthquake loads and to be able to use the elevator after the earthquake, and should be subjected to the required simulation with earthquake loads when designing and planning for the building. To progress towards this goal, international standards are published such as EN 81-77:2022, ASME A17.1. Earthquake standards for elevators differ between countries and regions (Sancak et al., 2021a). In this study, two different elevator bracket designs are examined for earthquake forces defined in International Standards and their simulations are run under certain parameters and assumptions. Then results have been compared.

Although it is not known in which direction the earthquake forces will act on the objects, it changes depending on some reasons. In the examination of earthquake forces, the highest dangerous situations that the earthquake force can affect should be examined (Sancak, 2020). It is thought that it will be safer to use bracket designs with lower stress values as a result of analysis compared to the standard bracket design in elevator facilities in areas where seismic loads are effective and high earthquake risk (Sancak et al., 2021b).

One of the critical point of the bracket is bolt mount points, where high stresses were seen (Elmali et al., 2012). There are studies on experimental stress analysis on the elevator guide rail and their comparisons with numerical results (Imrak et al., 2006). Improved safety during seismic activities is very important for both structural safety and reliability (Atay et al., 2014). For guide rails, most appropriate support distances should be chosen (Kayaoglu et al., 2011). Elevator car and counterweight make their vertical travel by means of guide rails and rail fasteners (Candaş et al., 2016).

Elevators are not used to avoid being stuck in the elevator during and after the earthquake. However, there are studies conducted to use elevators for evacuation in emergencies, especially in high-rise buildings (Andrée et al., 2016; Ding et al., 2021). Wang et al. (2017) modelled earthquakes in a real-scale five-storey building and stated that plastic deformation may occur in the rails as a result of different displacements of the bracket elements.

## 2 MODEL AND METHODOLOGY

Basics of earthquake, elevator bracket part, equations of earthquake force acting on elevators, and the proposed model are explained and discussed in this section.

### 2.1 Earthquake

Earthquakes are one of the most dangerous natural disasters that occur unexpectedly and causes instantaneous forces acting on mechanical systems. Earth's crust is made up of different pieces. Each piece of earth's crust is called a Plate.

Between the interacting tectonic plates, there is a frictional force that prevents the movement of the plates, and when this friction force is overcome, the plates move. Movement of tectonic plates creates earthquake waves that causes compression and tension of the ground. As a result, buildings and their systems are collapse. Ground shaking is expressed as Peak Ground Acceleration (Giardini et al., 2013).

### 2.2 Elevator Bracket

Elevator brackets connect the guide rails to the wall of the hoistway, allowing it to stand in a straight-linear structure. Brackets are also known as rail fastening systems. In Turkey, certification criteria TSE K 179 covers the requirements for characteristics and performance of fixing systems for elevator rails has been published in 2012 (TSE, 2012). According to this certification criteria, the bracket is made of at least S235JR (St-37) quality steel material whose tensile strength should be at least 360 MPa (TSE, 2012).

After major earthquakes occur in world, elevator survey reports for Van, Turkey 2011 (İmrak, 2012) and Miyagi, Japan 1978 (Asvestopoulos and Baliktsis, 2006) shows that the bracket damage as shown Figure 1 is one of the supreme failures for elevator systems. To minimize or eliminate this failure that occurred after the earthquake, elevator brackets of elevator systems should be investigated to understand whether brackets withstand seismic forces or are suitable or not.

***Figure 1. Damaged guide rail bracket (İmrak, 2012)***

### 2.3 Model

To investigate the seismic effects on the rail fastening systems, T90/B type guide rail which is commonly used in elevator installation is used to examine in this study. The concept model rail fastening systems including brackets, guide rail and rail clips is created according to the parameters listed in Table 1 (Sancak, 2020). Two different guide rail bracket designs are modelled and investigated under certain conditions. One is conventional bracket design and the other one is corrugated bracket design which are shown in Figure 2.

***Table 1. Elevator design parameters for modeling***

| Description | Symbol | Value |
|---|---|---|
| Elevator type | | Passanger Elevator |
| Passanger capacity | Q | 10 (or 800 kg) |
| Elevator car empty weight | $P$ | 1100 kg |
| Building storey | | 8 |
| Hoistway Length | $L$ | 25 m |
| Guide rail number of lines | $n$ | Symmetric, 2 line |
| Number of guide rails in one line | | 5 |
| Distance between car guide shoes | $h_p$ | 2200 mm |
| Elevator car dimensions | $C_w$, $C_d$ | 1350 mm, 1400 mm |
| | $C_h$ | 2200 mm |

The concept models of the bracket are taken from (Sancak, 2020). Because the conventional bracket design is more cost-effective than the corrugated bracket design, although the conventional bracket design is widely used in elevator installations in Turkey the corrugated bracket design is very rare. However, the strength of both bracket designs is different. The installation and sequence numbering of the 10 pairs of brackets on a guide rail can be seen in Figure 3.

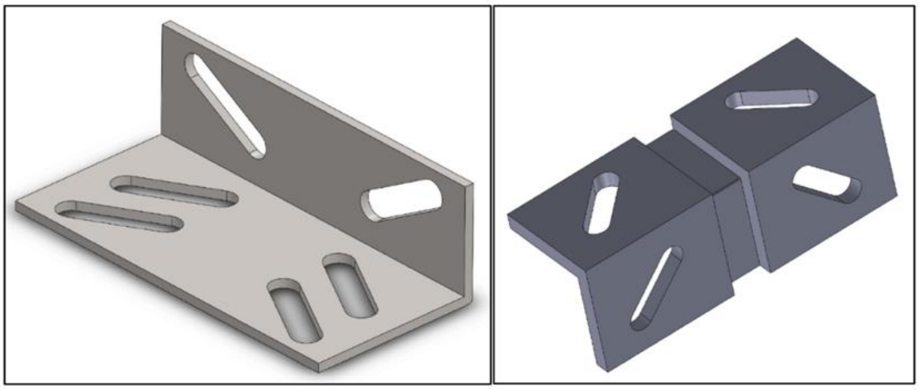

Figure 2. Conventional bracket (left), corrugated bracket (right)

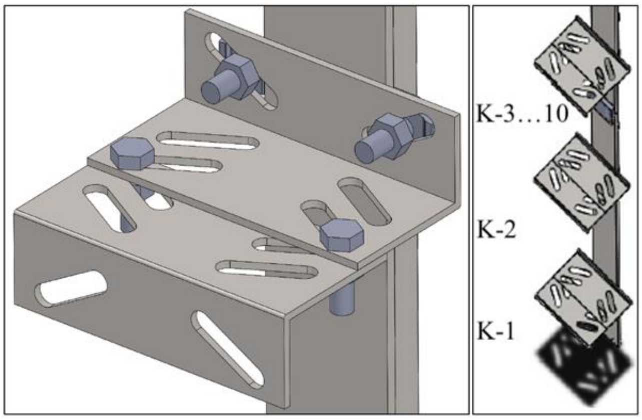

Figure 3. Installation of guide rail, bracket and other components

Solid model of guide rail and combination brackets are created using Solidworks 2017 SP5.0, © Dassault Systems. Then, for necessary finite element discretization and stress analysis, the generated model is transferred to the commercial software package ANSYS 19.2, © ANSYS Inc. Geometric optimization work is performed in accordance with the finite element analysis results.

The total length of the guide rails are 5000 mm x 5 pieces = 25000 mm and the distance between the guide rail brackets is 2500 mm. The full model of the building is used as 25000 mm. Analysis of the nuts and the bolts were not taken into consideration because boundary conditions are defined. In this study, to consider the deformation of brackets, nuts and bolts are accepted as fixed as they assembled and assumed they were not deformed, contacts were not separated. Therefore, the surfaces of the brackets mounted on the hoistway wall were considered as fixed supports and for bracket surfaces that contact with the guide rail were defined bonded contact with guide rail surface. Since the program did not give a solution by taking the solution to infinity while defining the friction force connection, the rails were accepted as rigid and the guide rail deformations were not examined. While the vertical forces on the rails are transferred to the brackets, the friction coefficient between the guide rail and the bracket multiplied by the force normal to the surface, thus the maximum force acting in the vertical direction is found. Contact faces of the bracket pairs were defined with friction coefficient and bonded contact. Seismic forces were applied to the selected sections at bracket assembled levels of guide rail.

The material selected for the guide rail is as per S235JR (St-37) and for guide rail brackets is as per S235JR (St-37) accordance with EN 10025-2 (CEN, 2019a). The material characteristics are taken as linear isotropic. The material properties for guide rail and guide rail brackets are shown below in Table 2. Contact properties between the guide rail and fixing systems are defined as global bonded conditions.

***Table 2. Material properties for guide rail and bracket modelling***

| Description | Guide Rail | Conventional Bracket | Corrugated bracket |
|---|---|---|---|
| Material | S235JR (St-37) | S235JR (St-37) | S235JR (St-37) |
| Yield stress | 235 N/mm$^2$ | 235 N/mm$^2$ | 235 N/mm$^2$ |
| Tensile stress | 440 N/mm$^2$ | 440 N/mm$^2$ | 440 N/mm$^2$ |
| Young’s modulus | 210,000 N/mm$^2$ | 210,000 N/mm$^2$ | 210,000 N/mm$^2$ |
| Poisson’s ratio | 0.3 | 0.3 | 0.3 |
| Mass density | 7.8 g/cm$^3$ | 7.8 g/cm$^3$ | 7.8 g/cm$^3$ |

The contact between the guide rail and bracket front surface is given bonded relation since they are fixed with each other clips and bolts. The domain of interest is divided into a collection of finite elements. The set of subintervals in a domain is called the finite element mesh of the domain. The mesh depends on the geometry of the domain and on the desired accuracy of the solution. In this study, the SOLID186, SOLID187, SURF154, MASS 21, TARGE170, and CONTA174 elements are selected and used for finite element modelling as shown in Figure 4.

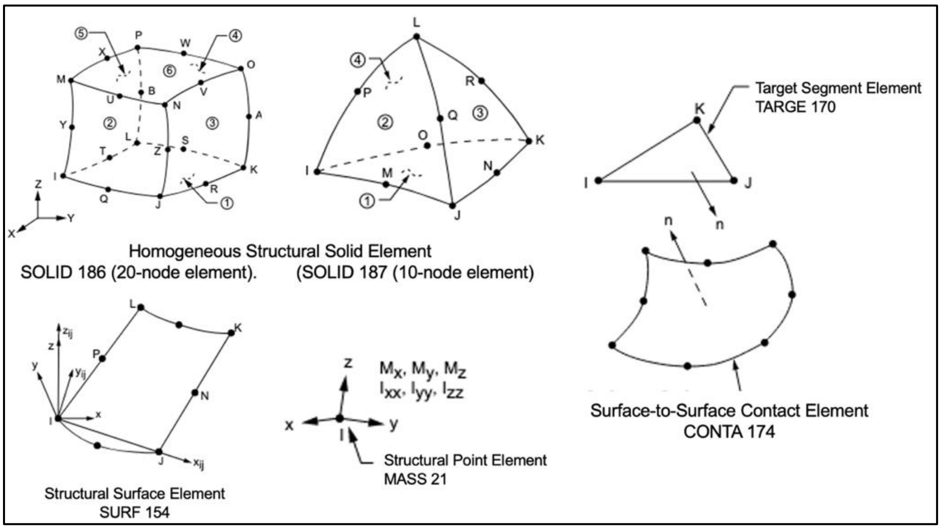

***Figure 4. Finite element types used in modelling.***

SOLID186 is a higher order 3-D 20-node solid element that exhibits quadratic displacement behavior SOLID187 element is a higher order 3-D, 10-node element. SOLID187 has a quadratic displacement behaviour and is well suited to modeling irregular meshes. SURF154 is used for various load and surface effect applications in 3-D structural analyses. MASS 21 is a point element having up to six degrees of freedom. TARGE170 is used to represent various 3-D "target" surfaces for the associated contact elements. CONTA174 is used to represent contact and sliding between 3-D target surfaces and a deformable surface defined by this element.

Details for mesh information for finite element modelling of guide rail fixing system is shown in Table 3. Total number of nodes for per simulation is 960,000 and total number of elements for per simulation is 350,000.

***Table 3. Element and mesh number in finite element model***

| Parameter | Guide rail | Conventional Bracket | Corrugated bracket |
|---|---|---|---|
| Mesh type | Quad8 | Tri6 | Tri6 |
| Element size (adaptive sizing on) | 5 mm | 5 mm | 4 mm |
| Average Skewness | 0.01 | 0.40 | 0.40 |
| Average Jacobian Ratio (Gauss) | 0.99 | 0.99 | 0.99 |
| Total nodes (per part) | ~150,000 | ~14,200 | ~14,400 |
| Total elements (per part) | ~36,500 | ~7,000 | ~7,600 |
| Max. aspect ratio | 34.07 | 56.89 | 18.90 |
| Average Aspect ratio | 1.03 | 2.4 | 2.4 |

In accordance with the deformation of the component and with time the lateral force acting on the guide rail and brackets does not change is contemplated. For this simulation linear static analysis is selected and the material property is considered elastic (Dubey et al., 2019).

## 2.4 Equations and Calculations

Seismic force acting on the guide rail and fixing system is taken from EN 81-77 (CEN, 2022) and ASME A17.1 (ASME, 2016). Centrally guided and suspended car is considered for system modelling. The analytical calculation of the forces is performed under normal running conditions as stated in EN 81-50 (CEN, 2019b). Bending stress with respect to Y-axis of the guide rail due to guiding force:

$$F_x = \frac{k_2 \cdot g_n \cdot \left[Q \cdot \left(x_q - x_s\right) + P \cdot \left(x_p - x_s\right)\right]}{n \cdot h}. \tag{1}$$

Bending stress with respect to X-axis of the guide rail due to guiding force:

$$F_y = \frac{k_2 \cdot g_n \cdot \left[Q \cdot \left(y_q - y_s\right) + P \cdot \left(y_p - y_s\right)\right]}{\frac{n}{2} \cdot h}. \tag{2}$$

Lateral forces acting on guide rail under normal running conditions:

$$F_v = (M_g \cdot g_n) + F_P. \tag{3}$$

where $k_2$ is the impact factor for the running condition, $g_n$ is the standard acceleration of free fall in metres per square second, $n$ is the number of guide rails, $P$ are the masses of the empty car and components supported by the car, i.e. part of travelling cable, compensating ropes/chains (if any), etc. in kilograms, Q is the rated load in kilograms, $h$ is the distance between car guide shoes, $F_p$ is the push through forces of all brackets at one guide rail (due to normal settling of the building or shrinkage of concrete) in newtons, $M_g$ is the mass of one line of guide rails in kilograms, $x_p$, $y_p$ is the position of the car mass (P) in relation to the guide rail cross coordinates, $x_Q$, $y_Q$ is the position of the rated load (Q) in relation to the guide rail cross coordinates,

$x_S$, $y_S$ is the position of the suspension (S) in relation to the guide rail cross coordinates.

Secondly, the analytical calculation of the forces as per safety gear actuation condition that is the worst-case condition is performed. The load is considered to be disperse to the one-third area of the car as stated in EN 81-20:2020 (CEN, 2020). The safety gear operation load distribution in lift car condition is selected to determine the center of gravity where:

$$x_q = x_c + \frac{Dx}{8}, \quad y_q = y_c\,, \quad x_c = x_s\,, \quad y_c = y_s, \tag{4}$$

$$x_p - x_c = 65\,mm, \tag{5}$$

$$y_p - y_c = 190\,mm. \tag{6}$$

The other required values are selected as:

$$M_g = 13.54\ kg/m\ , \quad k_2 = 1.2\,, \quad g_n = 9.81\,m/s^2\ . \tag{7}$$

With these parameters, one can calculate forces acting on guide rails during normal usage:

$$F_x = \frac{1.2 \cdot 9.81 \cdot [800 \cdot \left(\frac{1400}{8}\right) + 1100 \cdot (65)]}{2 \cdot 2200} = 566\,N, \tag{8}$$

$$F_y = \frac{1.2 \cdot 9.81 \cdot [800 \cdot (0) + 1100 \cdot (190)]}{\frac{2}{2} \cdot 2200} = 1119\,N, \tag{9}$$

$$F_v = (5 \cdot 13.54 \cdot 9.81) \cdot 5 = 3325\,N. \tag{10}$$

Lateral seismic forces acting on the brackets can be calculated in accordance with seismic force equations in ASME A17.1:

$$F_p = \frac{0.4 \cdot a_p \cdot S_{DS} \cdot g_n \cdot W_p}{\left(\frac{R_p}{I_p}\right)} * \left(1 + 2 \cdot \left(\frac{z}{h}\right)\right). \tag{11}$$

Vertical seismic force acting on the bracket can be written as:

$$F_v = \pm 0.2 \cdot S_{DS} \cdot W_p \cdot g_n. \tag{12}$$

where $F_p$ seismic component force, $F_{x\text{-}x}$, $F_{y\text{-}y}$ seismic force, $W_p$ total weight of car plus 40% of its rated load, or the total weight of the counterweight, $L$ vertical distance between the upper and lower position restraints, $l$ distance (rail span) between adjacent main guide-rail brackets, mm, $a_p$ component amplification factor p 1.00, $h$ average roof height of structure with respect to the defined building base, provided by the building structural engineer, $I_p$ component importance factor 1.00 or 1.50, $R_p$

component response modification factor 2.5, $S_{DS}$ 5% damped design spectral response acceleration for short period (ie, 0.2 s), *z* height in structure of point of attachment of component with respect to the defined building base provided by the building structural engineer. For items at or below the base, z shall be taken as 0. The value of z/h need not exceed 1.0.

In this study, we considered that *L= 2200* mm and *l = 2500* mm, because of *L < l*, thus the following equations can be written:

$$F_{x-x} = F_p \cdot \left(1 - \frac{L}{3 \cdot l}\right), \tag{13}$$

$$F_{y-y} = \left(\frac{F_p}{2}\right) \cdot \left(1 - \frac{L}{3 \cdot l}\right). \tag{14}$$

$F_a$ and $S_s$ values which are necessary for calculation for the above equation can be found in regional earthquake hazard maps. For this study, the earthquake hazards map of Türkiye (AFAD, 2018) is used. $F_a$ and $S_s$ value near the Bingöl province where the most dangerous place from the earthquake hazards map were found as:

$$F_a = 1.2\,, \quad S_s = 2.031, \qquad S_{DS} = 1.2 * 2.031 = 2.4372, \tag{15}$$

$$a_p = 1\,, \quad R_p = 2.5\,, \quad I_p = 15\,, \quad \frac{z}{h} = 1\,, \quad W_p = 1100 + 320 = 1420\,kg, \tag{16}$$

$$F_p = \frac{0.4 \cdot 1 \cdot 2.4372 \cdot 9.81 \cdot 1420}{\left(\frac{2.5}{1.5}\right)} \cdot \left(1 + 2 \cdot (1)\right) = 24450\,N, \tag{17}$$

$$F_v = 0.2 \cdot 2.4372 \cdot 1420 \cdot 9.81 = 6792\,N, \tag{18}$$

$$F_x = F_{y-y} = \left(\frac{24450}{2}\right) \cdot \left(1 - \frac{2200}{3 \cdot 2500}\right) = 8640\,N, \tag{19}$$

$$F_y = F_{x-x} = 24450 \cdot \left(1 - \frac{2200}{3 \cdot 2500}\right) = 17279\,N. \tag{20}$$

At the end of the calculations, the seismic forces are collected with the forces acting from normal use and applied to the model.

The friction force coefficient between the guide rail and the bracket was assumed to be 0.16. Thus, the maximum vertical force that act on the bracket is:

$$F_{v_{bracket}} = F_y \cdot \mu = 18398 \cdot 0{,}16 = 2944\,N. \tag{21}$$

## 3 RESULTS

Bingöl province where the most dangerous place from the earthquake hazards map. As a result, stress values were obtained by using the selected design parameters and assumptions for both bracket designs. The colourful plot diagram of finite element analysis results of the guide rail fixing system consisting of conventional bracket pairs are depicted in Figure 5a for K-3 and K-8 brackets. Similarly, the colourful plot diagram of the finite element analysis results of the guide rail fixing system consisting of bracket pairs developed in this study is shown in Figure 5b for K-3 and K-8 brackets.

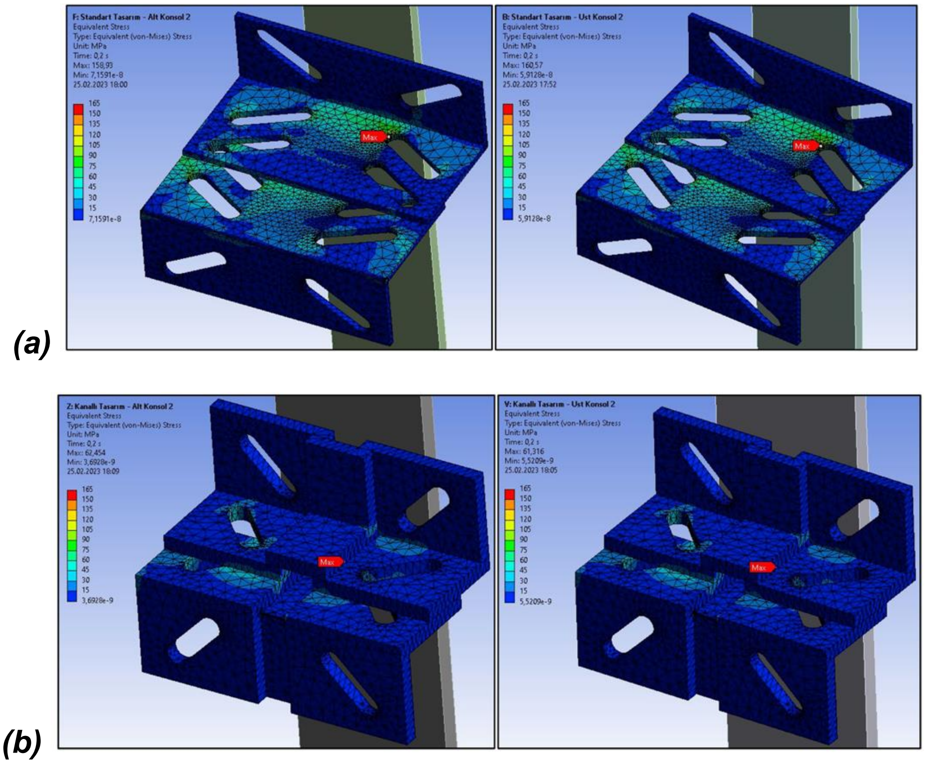

***Figure 5. FEA results of bracket design for K-3 (left), K-8 (right)***

In Figure 5, Scaling has been applied for stress values to see the difference clearly and make comparisons easily. According to the results of the FEM analysis, the maximum stress values of conventional and corrugated bracket designs were interpreted. The highest stress values are at K-3 and K-8 brackets, which are 3rd brackets of the top and bottom based on the position of the cabinet relative to the guide rail for both designs. One can read 158.93 MPa for K-3 bracket and 160.57 MPa for K-8 bracket in the conventional bracket design from the colourful plot diagram as the maximum stress value. Identically, one can read 62.45 MPa for K-3 bracket and 61.32 MPa for K-8 bracket in the corrugated bracket design from the colourful plot diagram as the maximum stress value.

It can be frankly said that the corrugated bracket designs have lower maximum stress values than the conventional bracket designs in any case at all operating conditions (normal running conditions and safety gear actuation conditions) during the earthquake.

## 4 DISCUSSIONS AND CONCLUSION

In accordance with the finite element analysis results, it can be seen that various bracket designs show variable deformation behaviours under earthquake conditions because of their geometry and topology. Although conventional bracket design is commonplace, reasonable and low price, it is proved that corrugated bracket design is stronger and more durable to seismic forces. The main reason for this is that the corrugated section reduces the stresses caused by the forces acting on the bracket and prevents the stresses from acting on a single fixing point. In fact, since the direction and magnitude of the forces occurring during the earthquake change stochastically, it is well known that it is very difficult to detect. Due to the instantaneous changes of these forces, higher stresses may occur than results obtained from computer models. Laboratory experiments to be carried out in the laboratory environment for the simulated studies are an effective way to detect and prevent the unexpected problems as much as possible.

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## 6 BIOGRAPHICAL DETAILS

**Abdülmelik SANCAK,** graduated from Marmara University, Engineering Faculty, Mechanical Engineering Department in 2017. In 2020, he completed the Mechanical Design Master's program at Istanbul Technical University, Faculty of Mechanical Engineering and received the title of M.Sc. Engineer. He carries out studies on transport systems, analysis of mechanical systems, structural analysis of elevators and their elements, and examination in case of earthquakes. He works as a Research Assistant at Istanbul Technical University, Faculty of Mechanical Engineering. He is still continuing his PhD and he is PhD Candidate in Mechanical Engineering which he started in Istanbul Technical University in 2020.

**Adem CANDAŞ,** has been employed as a lecturer in Istanbul Technical University (ITU). Dr. Candaş received the B.Sc., M.Sc. and Ph.D. degrees in Mechanical Engineering from ITU in 2010, 2013, and 2021 respectively. He had the M.Sc. degree in Geodynamics in 2017. He has carried out research into fracture mechanics, computer aided engineering, numerical analysis, materials handling and especially lift systems.

**C. Erdem İMRAK,** has been employed as a fulltime Professor in Istanbul Technical University (ITU). Professor Imrak received the B.Sc., M.Sc. and Ph.D. degrees in Mechanical Engineering from ITU in 1990, 1992, and 1996 respectively. He has carried out research into computer aided engineering, CAD/CAM, numerical analysis, materials handling and especially lift systems. Currently his activities include: a Honorary Member of ASYAD; a Member of Safety, Education & Training Committee of ELA; a Member of the ASME; a Member of the OIPEEC; a Member of the IAEE; a Member of Chamber of Mechanical Engineers in Turkey.

**Sefa TARGIT** graduated from the Division of Industrial Engineering, Faculty of Mechanical Engineering at Istanbul Technical University. After graduation in 1982, he worked as the mechanical installations engineer in various construction companies and in 1992, he joined ASRAY and thus, the manufacturers side of the Lift Industry. He is currently a partner and the General Manager of ASRAY; Vice President of MAKFED (Turkish Machinery Federation). He is a member of the Board of IAEE; Lift Technical Committee of Ministry of Industry; MMO Turkey (Chamber of Mechanical Engineers). He is currently a member of ELEVCON Steering committee. He is also Former President of AYSAD (Turkish Elevator and Escalator Association); and SEDEFED (Federation of Industrial Associations of Turkey).