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INVESTIGATION OF THE STRESSES AND STRAINS OF STEEL COLUMN-BEAM CONNECTIONS SUBJECTED TO SEISMIC LOADING

E. Çınar YENİ,
Dokuz Eylul University, Department of Mechanical Engineering,
Bornova, Izmir, Turkey. emine.cinar@deu.edu.tr
Binnur GÖREN
Dokuz Eylul University, Department of Mechanical Engineering,
Bornova, Izmir, Turkey. binnur.goren@deu.edu.tr

Abstract-In Turkey most of the buildings are constructed using concrete, while it is known that concrete is a brittle construction material unsuitable for countries prone to earthquakes. Therefore in other earthquake prone countries such as Japan and USA steel column-beam connections are widely used. It is accepted worldwide that these types of structures are more resistant to seismic loading compared to concrete structures. The steel column-beam connection region is the most critical part for steel framed structures in terms of various factors such as the materials employed, the type of connection, the degree of seismic loading, etc. In this study, a welded column-beam connection was modelled using I-DEAS software and finite element analysis was carried out on the model in order to conduct the stress-strain analysis.

Keywords-Steel welded column-beam connections, seismic loading, finite element modelling, cyclic loading.

1. INTRODUCTION

1.1 Background

The Marmara earthquake on August 17, 1999 of 7.4 magnitude caused a devastating catastrophe and great human tragedy for the Turkish people. Thousands of people died in the numerous collapse of concrete buildings, which is the predominant structural system used for buildings in Turkey. It is a common practice in countries prone to earthquakes like USA and Japan to build large scale industrial and/or residential buildings using steel columns and beams. It is accepted worldwide that these types of structures are more resistant to seismic loading compared to concrete structures. The steel column-beam connection region is the most critical part for steel framed structures in terms of various factors such as the materials employed, the type of connection, the degree of seismic loading, etc. Column-beam connection is obtained most of the time by welding; however bolted connections are sometimes used. By taking necessary precautions and ensuring the required specifications, the damage to steel framed structures in an earthquake compared with concrete structures will be much less. The use of steel framed structures is only recently gaining acceptance in Turkey. It is crucial that the conventional concrete building system be modified or new building techniques are employed in order to reduce human and property losses in earthquakes.

Today, the predominant structural system used for buildings in Turkey consists of reinforced concrete frames with unreinforced masonry infills. This structural form is used for all building heights and occupancy, from single story commercial to multistory residential and office buildings. Industrial buildings are either reinforced concrete (cast-in-place or pre-cast) or steel frame structures. [1]

The damage to reinforced concrete buildings from this earthquake can be attributed to one or more of the following:

1) Foundation Failures: Especially observed for a large number of buildings with large settlements, and in some cases, entire structures overturned.
2) Soft Stories: A large number of residential and commercial buildings were built with soft stories at the ground floor level. These are often used as stores or commercial areas. Generally, heavy masonry infills start immediately above the commercial floor. During an earthquake, the presence of a soft story increases deformation demands very significantly and puts the burden of energy dissipation on the ground-story columns. Many failures and collapses can be attributed to the increased deformation demands caused by soft stories, coupled with lack of deformability of poorly designed columns.
3) Strong beams and weak columns: Most frame structures have strong beams, remaining elastic and weak columns suffering compression crushing or shear failure. In many cases, relatively deep beams were used with flexible columns, contributing to the strong beam-weak column behavior. [1]

Most of the structural damage observed in steel frame buildings was concentrated at column ends. Unfortunately, confinement reinforcement virtually did not exist in these members, making them unable to maintain the required ductility. Moreover, geometric irregularities such as eccentric beam-to-column connections induced severe torsion in short perpendicular stub beams.

An alternative to concrete, steel, by far the most expensive construction material in Turkey, has been used rather sporadically in construction; only industrial structures rely on steel for their lateral load resistance. Some were damaged by this earthquake and only a few have been collapsed. The main collapse was generally at the column-to-beam connection in the form of tearing of the weld connecting columns-to-beams, fractures of brace connections, buckling of braces. Other collapses included failure of anchor bolts at column bases and structural instability under overturning forces. Still other evidence of damage includes local buckling in concrete filled steel hollow pipes used as wharves.

It has been observed that in structures designed and constructed by modern engineering methods, such as the transportation systems and industrial facilities. In these cases, relatively little damage had occurred. [1]

i) Damage to Steel Frame Structures in Kobe, Japan and Northridge, USA Earthquakes

In 1995 Kobe earthquake, in a steel construction expressway, some of the welded box type steel columns were crushed in compression under the high level of vertical ground acceleration due to brittle fracture of welded parts, separating the four sides of the box column into four independent plates. This is reminiscent of brittle fracture of welded joints of steel frame buildings in Northridge, USA earthquake in 1994.

In Kobe earthquake relatively for steel buildings were observed to have significant damage. Most of them were in a town complex, about 10 to 29 stories, built in the 1970's and are of nonconventional construction. That is the structure consists of large trussed steel column-beam frames. Some highways and railways were also damaged. [2]

ii) Comparison of Steel and Concrete as Building Materials

In Turkey the ratio of steel usage per m^2 in constructions is about 5%; this ratio is 30% in Germany and France, 50% in Scandinavian countries, over 50% in England and about 30% in Mediterranean countries. Steel construction is especially widespread in multistory building applications.

In an earthquake, the ductility (the deformation ability of a material under force) of a material is important. [3]

1.2 Advantages of Steel

The fracture of concrete under compression is 3.5-7 in 1000 or it has 1% deformation tolerance; this is minimum 18% in steel, that could go up to 30%. This means that steel in 18-30 times more ductile than concrete. This is the most important characteristic of steel is relation with earthquake. Another advantage of steel over concrete is that the inspection of steel structure after construction is easy, since the structure is open; the inspection of concrete once it has been cast is harder.

One more advantage is that steel is a material that allows for rapid construction, it starts to function as soon as it has been placed into its location.

The following facts can be listed as disadvantages, though not all are unique to steel constructions:

Steel is more expensive than concrete. Steel is prone to corrosion, for this reason it has to be painted. But concrete also includes steel and this steel inside concrete also rusts.

Fire strength of steel is low; it looses its specifications over 600°C. Again, this is also true for steel inside concrete.

The hazards attributed to steel, therefore, hold true for concrete, too. But steel in the latter case, is protected more with concrete. [3]

As a conclusion, concrete and steel shouldn't be rivals of each other. They should be used together. Concrete withholds compression type forces and steel withholds tension type forces better. If steel is dangerous due to excessive flexibility, it can be compensated by concrete. Moreover, cost can be reduced by employing steel and concrete together.

The weld used in steel constructions is better done in the workshop rather than in the field, since the percentage of error rises in the construction site. Examples of this can be seen in Kobe [18]. In Turkey; in general, welding is conducted in the workshop, and pieces are mounted by strong bolts.

The Northridge-USA, Kobe-Japan and Marmara earthquakes highlight the need for structural engineers to remain current with research and state-of-the-art practice. The finding of brittle fractures in steel frames after that event suggests that we should occasionally re-examine the validity of our traditional practices. Brittle fracture has contributed to past building and nonbuilding structural failures. Fracture characteristics, well understood in some specialised fields, have not been sufficiently considered in the design of steel structures resisting earthquake demands.

2.1 Connection Details

Column-beam connections (also called moment resisting frames) are widely used for seismic-resistant steel construction. Column-beam connections achieve ductile response through flexural yielding of the beams or shear yielding of the column panel zone. The beam-to-column connections must be capable of developing and maintaining the strength of the beams or panel zones.

The most typical details of beam-to-column connections are given in Figure 1, which is designed to fulfil requirements for fully restrained moment connections. [5,6]

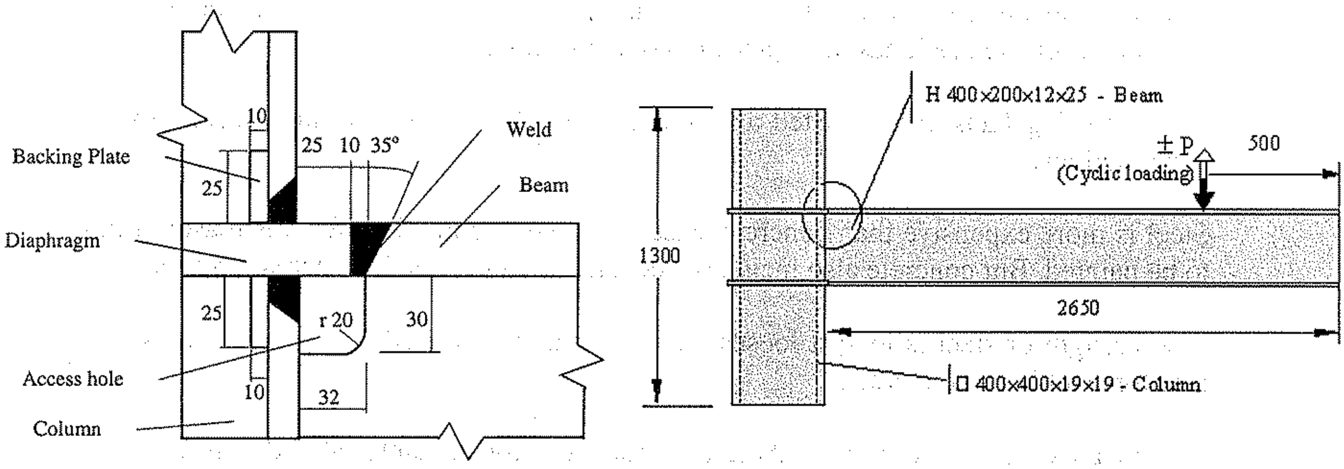


Figure 1 Column-beam connection design

3. ANALYSIS AND DISCUSSION

The purpose of this study is to investigate moment-resisting beam-to-column connections during the earthquake. In the countries prone to earthquakes such as Japan and USA, the aim is to achieve primarily strong column-weak beam connections in the design of steel buildings. In the analyses, steel welded beam-to-column connection model (Figure 1) widely used in literature and practices was examined [1]. This connection assembly comprised a box profile 400×400×19×19-column with the plates (backing plates and diaphragm in Figure 1) to a H-profile H 400×200×12×25-beam. It has been modelled by using the I-DEAS Master Modeller Software.

Figure 2 shows the finite element meshes and boundary conditions used in the analyses. The model consists of about 4000 solid finite elements. The model is clamped at the end of the column at A, and the support at the end of the beam at B is a roller joint which can slide along the z direction.

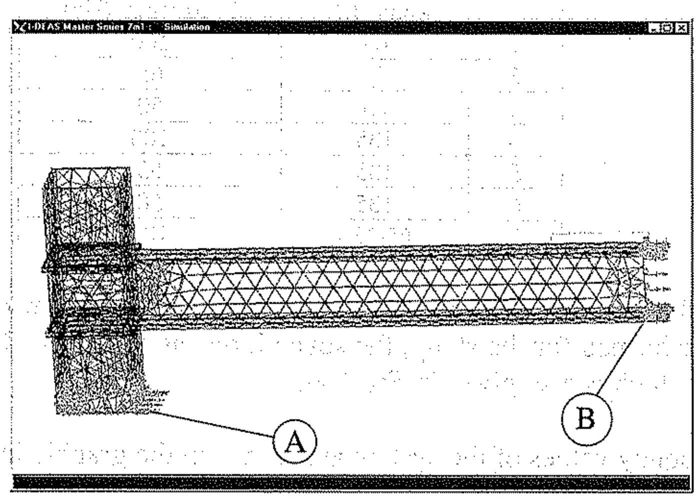
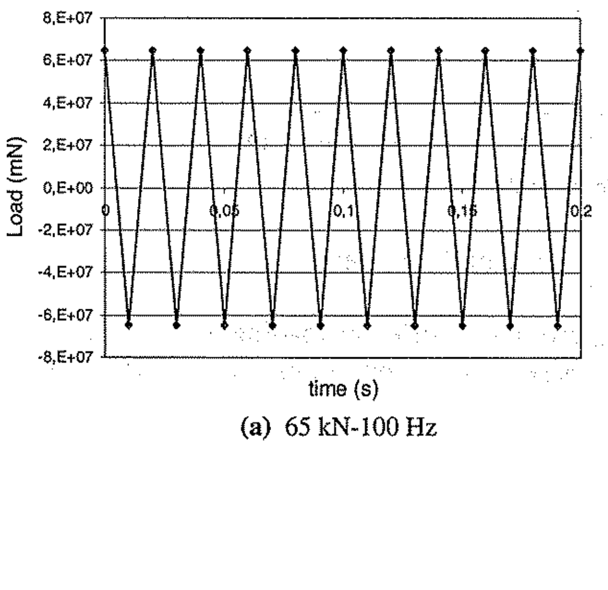
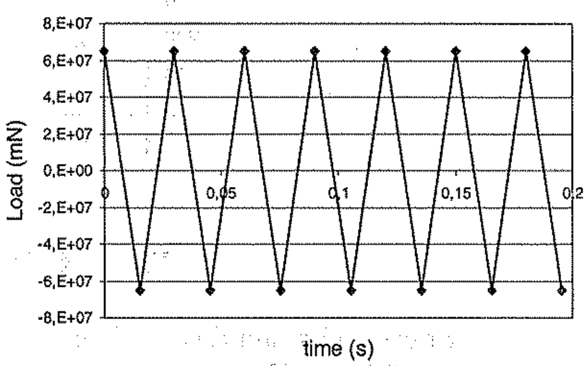


Figure 2

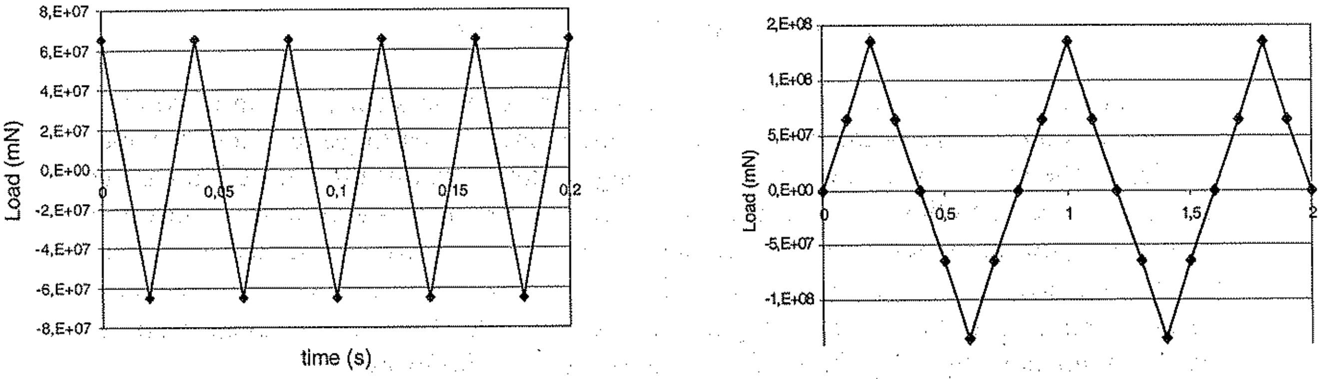
Seismic loads are simulated as cyclic loading [16]. The model was loaded to 65 kN and 135 kN magnitudes for three different frequency values (100 Hz, 65 Hz, and 50 Hz) such as shown in Figure 3.



(a) 65 kN-100 Hz



(b) 65 kN-65 Hz



(c) 65 kN-50 Hz (d) 135kN-65 kN-100 Hz

Figure 3 Various Loading Conditions

Table 1 Applied Loading Conditions

	Load (kN)	**Frequency (Hz)**
1	65	100
2	65	65
3	65	50
4	135	100
5	135	65
6	135	50
7	65-135	100

Table 1 shows the loading conditions applied to the column-beam connection. Seven analyses were performed for the study, the seventh one as seen from Table 1 consists of varying loading which is also given in Fig. 3-d.

The natural frequency values of the system are shown in the graphic in Figure 4.

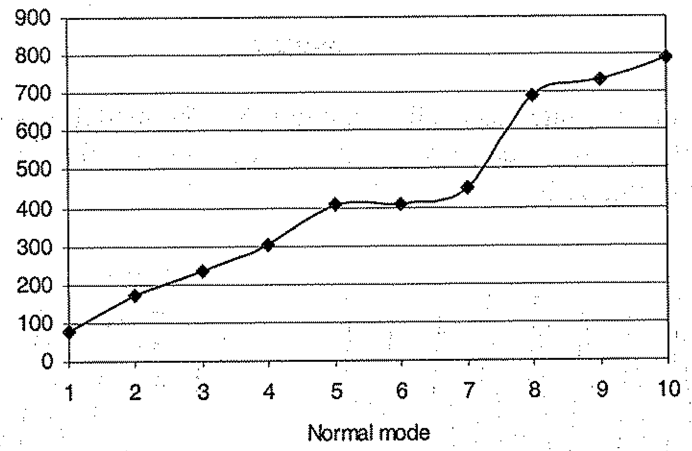
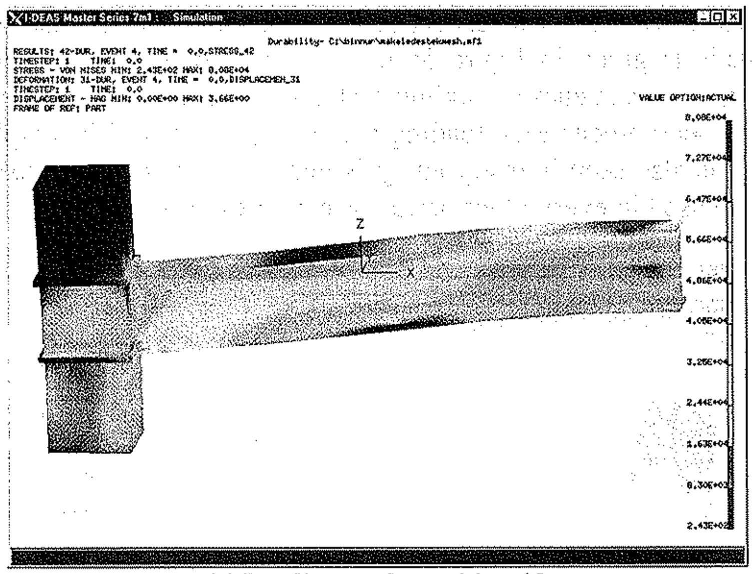
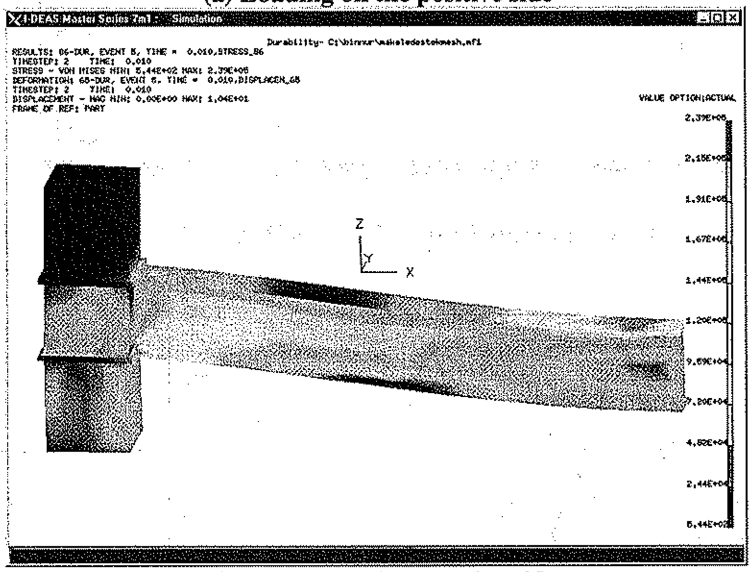


Figure 4 Natural Frequencies of the System

Stress and strain distributions were investigated under different loading and frequency conditions. Experimental studies under these same conditions were made by Aenglehardt and Husain [17].



(a) Loading on the positive side



(b) Loading on the negative side

Figure 5 Stress Distribution in the Column-Beam Connection Area

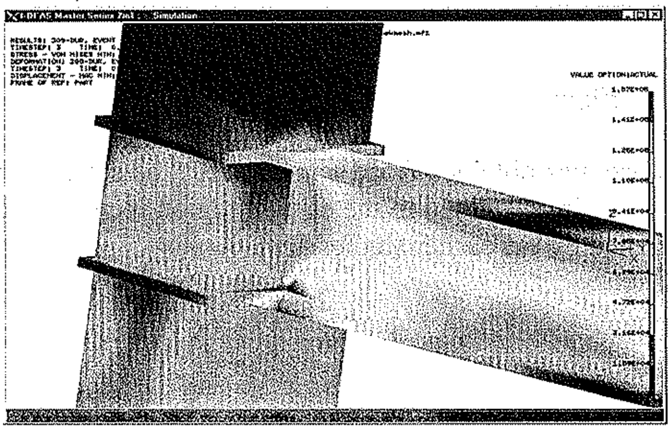


Figure 6 Stress Distribution in the Critical Region (Diaphragm-Beam Connection Region)

The general stress distribution wit respect to the application of the load to the positive and negative z-axis is given in figure 5a and 5b. Independent of the effect of these variables (loading and frequency), maximum stress concentration occurred at the weld connection on the beam under each loading condition, Figure 6. The displacements are given in Fig. 7. It is also seen in every analysis that the value of strain examined in the critical region increased in every other period as expected, Figure 8.

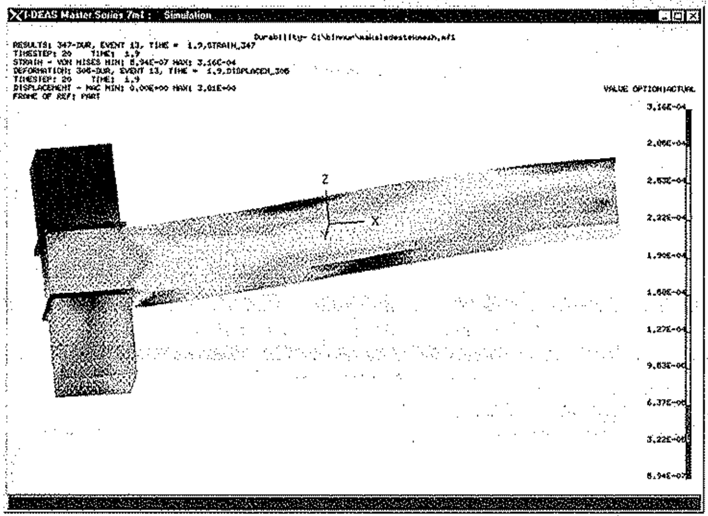


Figure 7 Displacements in the Column-Beam Connection Area

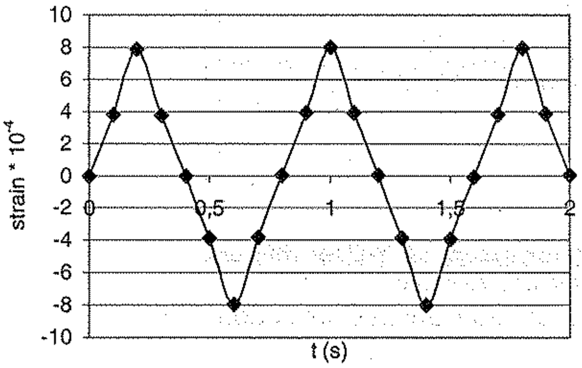


Figure 8

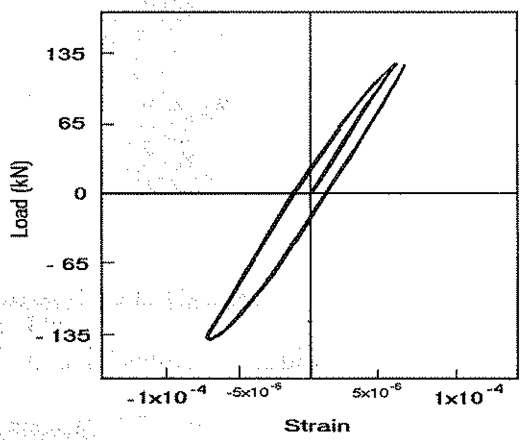


Figure 9

The hysteretic response was obtained (load versus strain) as seen in Figure 9, it is also seen that the value of strain examined in the critical region increased in the next period. This condition is verified by the earlier studies [18].

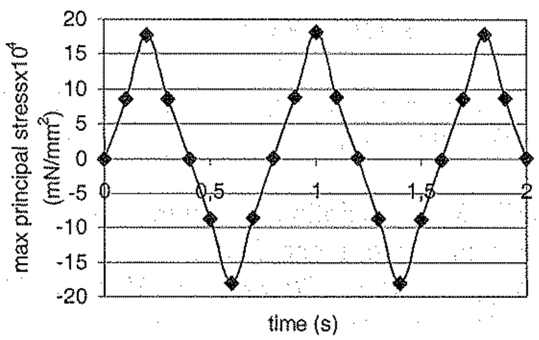


Figure 10

In examining the stress distributions, it is also seen that the stress values increased in every other period as in the case of strain, Figure 10.

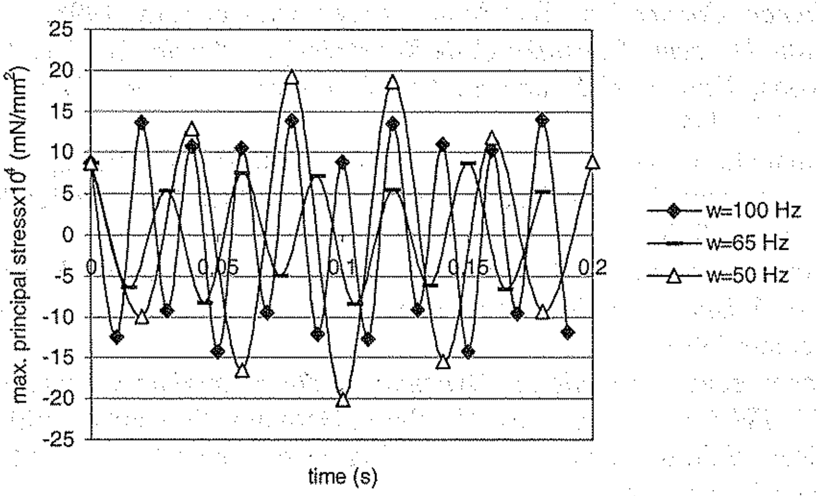


Figure 11

Figure11 shows the effect of frequency of the load on the stresses. The principle stresses were taken into consideration in order to better visualise the effect of frequency on the stress values. The graphic was drawn for 100 Hz, 65 Hz, and 50 Hz versus 135 kN, the graphic for 65 kN is similar to the one for the 135 kN. As seen, the stress values are the maximum when the frequency is 50 Hz since the application time of the loading is the greatest.With a similar assumption, it was expected that the stress values would be greater for 65 Hz compared to 100 Hz, while the opposite has been realised. The reason for this could be the increased frequency against short application time.

4. CONCLUSION

In this study, it has been seen that the stress values experienced on the critical region on the column-beam connection are not linearly dependent on the frequency. Also the stress and strain values increase with every other period. Further justification on these subjects are required. Experimental and more comprehensive numerical studies are planned for the future.

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