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Behavior of Steel Braced Frames Made of Tapered I Sectıon Members

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Keywords

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Seismic load,
Braced frame,
Finite Element model,
Hangar.

Abstract

Industrial buildings consist of an important part of steel constructions in Turkey. These structures, which are generally used to cover large spans, are formed by bringing one or more frame systems side by side. Steel materials is used more than reinforced concrete in such structures due to the lightweight and high strength. In this study, the tapered steel I section is used to model a hangar in Samsun province. Finite Element analyses are carried out to perform the behavior of the hangar under seismic loads. The hangar has a single span system with a width of 16 m and a length of 20 m and a height of 7.5 m. In this study, IPE profile in columns, trusses and purlins, and box profiles in side X braces. Sap2000 software is used for Finite Element models to investigate the mechanisms of the hangar made of tapered steel I sections. The study aims to perform intensive parametric studies to provide a depth understanding of the advantages of tapered cross-sectional models corresponding to the constant cross-sectional models. It is found that the models made of tapered I section members have 8 % less weight than the corresponding constant section members. As a result of that, it may be possible to reduce to construction cost by using tapered steel I sections since this also decrease the seismic load effects in the hangar compared to the constant cross-sectional model.

1. Introduction

Industrial buildings take place in a significant part of the investments in the construction sector. This type of structure is the preferred type of building for covering large volumes. It is of great importance that the static system of these types of industrial buildings is selected properly and it provides the economic implementation of this structure [1].

Nowadays, the use of steel material in the design of many buildings is less than reinforced concrete structures. This ratio is the opposite for industrial buildings. The most important reason for this situation is that the completion time is short and it can be put into operation immediately. In addition to covering large spans, the lightness of the steel structures are less affected by the earthquake, and therefore it is possible to design more economical structures.

Structures with a single-storey rigid steel frame system are made for various purposes. Especially in such structures, to ensure the most effective use of structural steel, the tapered members might be considered an ideal system. Tapered members provide relatively lightness and of course, most importantly, economy by comparing to the regular members [2].

Aydeniz [3] studied the tapered members in a factory building. Analysis of the structure was made under static and dynamic effects using the SAP2000 package program. Akgöz [4] examines the buckling analysis of columns of tapered cross-section under an axial compressive load. It is taken into account that the cross-section constantly changes along the length of the column. A detailed parametric study was carried out to investigate the effects of cone ratio and boundary conditions on the buckling loads of tapered columns.

Jin, et al. [5], recently developed constrained shell finite element for the analysis of elastic buckling of thin-walled elements and their applicability to conical steel sections using a set of numerical examples. They introduced a method to calculate their resistance. Tankova et al. [6] carried out both experimental and numerical studies on the buckling behaviour of web tapered I-section steel columns, considering stocky and slender columns. The test results were used to validate the numerical models in Abaqus software.

Quan et al. [7] worked on the tapered I-section member to evaluate the second-order effects. They defined the failure of the member by limiting the strains. They compared the results of their new method with the predictions of the Eurocode 1993-1-1 [8] design guide. The proposed method was recommended.

As shown in the literature studies mentioned above, the use of variable cross-section elements is not very common. However, it may become more popular as the research on the tapered members increase. Therefore, this study aims to perform intensive parametric studies to provide a depth understanding of the advantages of tapered cross-sectional models corresponding to the regular cross-sectional models.

2. Numerical parameters

In this study, tapered steel I-section was used to design a hangar as shown in Figure 1. The hangar was also designed by regular members to be able to compare the results with the design of the hangar made of tapered members. Therefore, two identical structures with regular and tapered cross sections were performed. Turkish design guide for steel structures [9] was taken into account to determine the structural members. Approaches of design with load-resistance coefficients (YDKT) were used and Table 1 summarises the loading combinations.

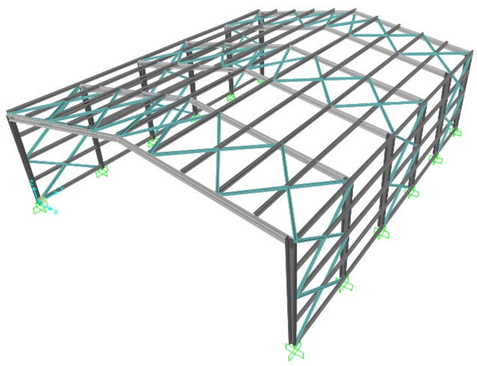


Figure 1. Structural model used in the parametric study

The hangar made of regular steel cross-sections was designed based on the Turkish design guide [9]. After that, the same structure was designed by using tapered I-section members as summarised in Table 2. To generate the appropriate tapered member, the regular steel sections were cut as shown in Figure 2. Figure 3 illustrates how to create the tapered I section by welded two cutting pieces in Figure 2.

Table 1. Combinations used (YDKT) [9].

KOMBİNASYONLAR	
1.4G	1.2G+1.0Q+0.5S+1.6W
1.2G+1.6S	1.2G+1.0Q+0.2S+1.0EX
1.2G+1.6Q+0.5S	1.2G+1.0Q+0.2S+1.0EY
1.2G+1.6S+Q	0.9G+1.0EX
1.2G+1.6S+0.8W	0.9G+1.0EY
0.9G+1.6W	

Table 2. Cross section values (mm).

	Members	Section
Regular sections	Columns	IPE300
	Beams	IPE300
Tapered sections	Columns	IPE270/200-340
	Beams	IPE270/340-200

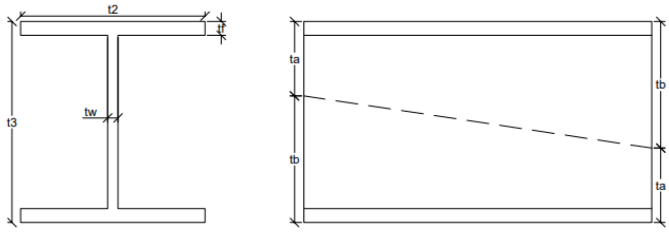


Figure 2. Tapered cross-section made of IPE270.

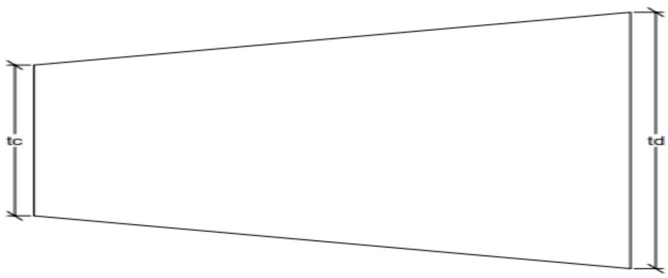
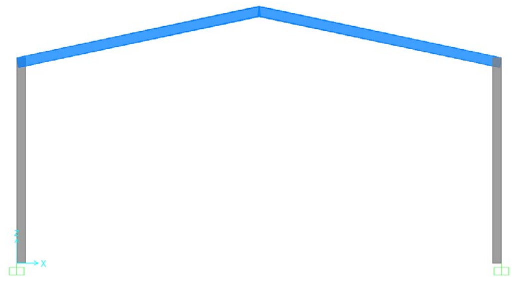
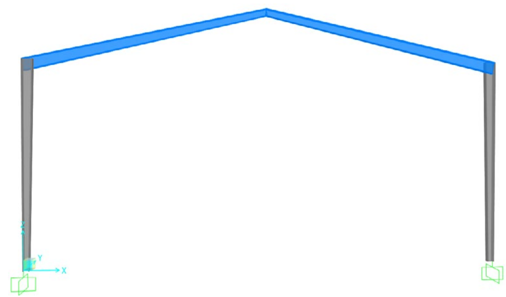


Figure 3. Typical tapered I-section used in the parametric study.

Figure 4 shows both the portal frames made of regular and tapered members in the parametric study. The profiles used in the numerical analyses are shown in Table 2.



a) Portal frame made of regular members



b) Portal frames used in numerical analyses.

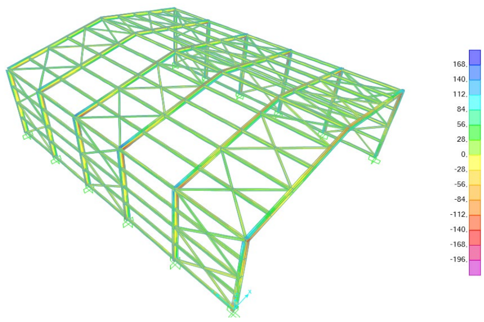
Figure 4. Regular *cross-section model.*

3. Analysis Results

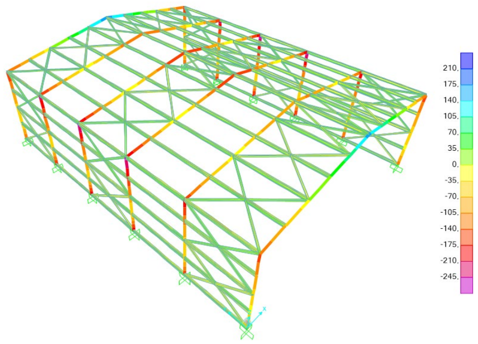
Finite element analyses were carried out by using Sap2000 software. The behaviour of the hangar under seismic loads was examined by comparing the stress distributions in the tapered beams, the maximum horizontal deformations at the top of the tapered columns and the self-weight of the structure with the results of the corresponding structure made of regular members.

Figure 5 compares the stress distributions in the structural models made of regular steel members with the tapered steel members. As can be seen from the comparison that the stresses in the hangar made of regular members are distributed scarcely compare to the tapered model. The reason for that the cross-section is used more economical than the corresponding structure. Because the section sizes are determined based on the critical member which is exposed to higher loads than other structural members.

The maximum horizontal deformations at the top of the columns in the hangar made of regular and tapered members are 15 mm and 23 mm, respectively.



a) Made of regular members



b) Made of Tapered members

Figure 5. Comparison of stress distributions in the structural model *made of regular or tapered members*

4. Discussion of the Numerical Results in Terms of Cost

In this study, it was mentioned that the modelling of tapered cross-section members has economic results. It has been revealed as a result of the calculations that the use of tapered cross-section members reduces the weight of the structure by 8%. This change in the weight of the building had a positive effect in terms of cost, as smaller steel sections were used. At the same time, the decrease in the weight of the building may also have a positive effect on the cost during the foundation process. However, labour to generate the tapered cross-sections may have a negative effect on costs. In this study, the weight of the building has been examined as a result of the modelling and design. The self weights of the structures made of the regular and the tapered members are shown in kN in Table 3.

Table 3. Comparison of building weights between regular and *tapered steel member structures.*

Member Name	Regular cross-section(kN)	Tapered cross-section(kN)
Cross	34.13	34.13
Purlin	83.89	83.89
Beams	40.99	28.46
Columns	40.99	38.61
Total	200	185.09

The total weight of the regular cross-section structure was calculated as 20.39 tons. The total weight of the variable cross-section structure was calculated as 18.87 tons. There is a difference of 1.52 tons between them. To show as a percentage, the structure with regular cross-section is 8.06% heavier than the structure made of the tapered cross-section.

5. Conclusion

In this study, two different analyzes of the steel hangar project were examined. The investigations aim to examine the hangar made of regular and tapered steel members and to reveal in which conditions the use of tapered cross-section provides advantages. For this purpose, the steel hangar was firstly modelled with regular cross-sections. After determining the regular cross-sections for each structural member based on the Turkish design guide [9]. Then, the tapered cross-section structure was modelled by only revising the columns and beams as tapered members and re-analyzing the corresponding tapered model under the same loadings. It has been determined that tapered steel members can be used to design the steel braced frames by using smaller members compared to the hangar made of regular members. The the IPE300 was used for 6 m high column in the regular structural system while the IPE270 was sufficient for tapered structural system. Likewise, this is the case with regular and tapered beams.

The detection of crossing the same span with a smaller profile is the desired and expected event in this study, as well as explaining the situations in which variable cross-section profiles are preferred. One of these situations is that it is used to pass large openings. To explain this situation in more detail, if a large span is passed with a fixed cross-section profile, the profile is dimensioned according to the most critical point, and this situation is used in the place that is subject to a very low load, so the economy disappears, but this problem is eliminated if modeling is done as a variable. While the higher profile is used in the critical place, the profile size can be reduced where there is less loading. For this purpose, cost analysis and evaluation can be made.

It was mentioned in this study that the other reason why tapered section modelling is preferred is also based on lightness. In this case, it can be stated as follows, since the profile size used in the regular cross-section is larger, the tapered profiles will be lighter, this lightness has been obtained by calculating around 8%. This situation will inevitably provide economic gain to the regular system and it is one of the reasons to be preferred.

In summary, the result of this study shows that tapered sections give more economical results than regular sections in dimensioning such an industrial building, but these results do not mean that they will give the same results in different building types. In the construction sector, it should be aimed to provide optimum engineering service by considering time, cost and budget concepts while projecting and implementing them.

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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