



## APPLICATION OF MODERN SEISMIC CODE PROVISIONS TO EARTHQUAKE RESISTANT DESIGN OF STEEL BUILDINGS

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### ABSTRACT

Exceptional circumstances may be encountered in the design of important buildings located in seismic areas. In these cases, state-of-the-art earthquake engineering approaches, which are currently adopted by existing codes or under consideration for future code revisions, have to be followed.

Some special situations may be encountered in the design of specifically large span steel structures subject to gravity loads and seismic effects. Among these are the global stability verification of large span roof structures and the consideration of vertical seismic effects. Also, the design of connection systems those link together building blocks that are structurally independent or exhibit different dynamic properties and behaviour, should be taken into account.

Methodology adopted for these special cases and examples of implementation of such procedures in the design of the New Domestic Terminal at Adnan Menderes Airport in İzmir are the subject of this presentation.

It is anticipated that, the above mentioned modern approaches will be incorporated into associated Turkish Standards and new provisions of future Turkish Seismic Code.

### INTRODUCTION

Consideration of vertical seismic effects is crucial in the design of large span structural steel roof systems built in high seismic zones. Vertical seismic analysis is typically performed through employing a vertical seismic design spectrum obtained, based on the local seismicity data or a ratio of the horizontal seismic design spectra. Internal forces resulting from such analysis is combined accordingly, with internal forces obtained from other load conditions as well as those attributable to horizontal seismic effects.

Large span roof structures should also have sufficient redundancy with regards to second-order effects and global buckling. Second-order effects may have a significant impact on the ability of structures to resist collapse when subjected to strong ground shaking. The global buckling safety of the roof structural systems may be accomplished through a second-order elastic analysis.

Another challenge encountered in the structural design of large structural complexes comprised of several building blocks is the prevention of loss of gravity support of connection systems due to relative deformations of such separate building blocks or parts of blocks that exhibit dissimilar dynamic characteristics.

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The purpose of this paper is presentation of modern approaches and design methodology employed per various code provisions to address the special design challenges encountered in the structural design of İzmir Adnan Menderes Airport New Domestic Terminal.

## GLOBAL STABILITY ANALYSIS

In large span structures such as the barrel vaulted roof system over the departures hall of the New Domestic Terminal, system-wide global stability analyses have to be performed in addition to individual element based stability checks.

The barrel vaulted roof system is a single layer diagrid system covering a plan layout of 200 m by 80 m over the main departures hall of İzmir Adnan Menderes Airport with a clear span of 72 meters, Figures 1 and 2. The roof system is supported by four major diagrid hyperboloid funnel structures ranging from 15 to 20 meters in diameter at their base. The diagrid roof members are 40 cm wide and 60 cm deep rectangular hollow built-up sections. A total of 1752 pieces of diagrid members are rigidly connected at a total of 829 joints each with 32 pcs. of M30 (ISO 10.9 quality) fully torqued HR type bolts. The roof system is supported on 90 cm (wide) by 180 cm (high) reinforced concrete beams spanning continuously across reinforced concrete-steel composite columns. While the airside axis of supports are fully fixed, the supports at the landside axis are transversely fixed however free to rotate about the support axis.



Figure 1. Perspective view of the barrel vaulted roof structure above the departures hall of İzmir Adnan Menderes Airport New Domestic Terminal Building

For non-seismic applications, displacement limits are commonly used in design to assure the serviceability of the structure. However, the situation is somewhat different while considering seismic effects. Research has shown that such displacement limits, although primarily related to serviceability,

also enhance frame stability and seismic performance due to subsequent additional strength and stiffness, provided. Second-order ( $P-\Delta$ ) effects may have a significant impact on the ability of structures to resist collapse when subjected to strong ground shaking. If earthquake induced displacements are sufficiently large to create negative instantaneous stiffness, collapse is likely to occur. Therefore, ASCE 7.10 Code limits the ratio of secondary moments to primary.



Figure 2. Interior view of the barrel vaulted roof structure above the departures hall of İzmir Adnan Menderes Airport New Domestic Terminal Building

The global buckling safety of the roof structural system above the departures hall is checked through a second-order elastic analysis. The second-order analysis has been performed by using an approach similar to the provisions of AISC 360.10.

Effects of all the following factors on the stability of structure and its elements should be considered:

- (1) flexural, shear and axial member deformations, and all other deformations that contribute to displacements of the structure,
- (2) second-order ( $P-\Delta$ ) effects, which consider the effect of geometrical changes on equilibrium equations,
- (3) effect of geometrical imperfections on the stability of the structure,
- (4) stiffness reductions due to inelasticity.

All load-dependent effects shall be calculated at a level of loading corresponding to 1.6 times allowable stress design combinations.

The analysis of the structure to determine the required strengths of components should use reduced stiffnesses, as follows:

A stiffness reduction factor of 0.80 is applied to all structural elements that are considered to contribute to the stability of the structure.

The effect of initial imperfections on the stability of the structure can be taken into account either by direct modelling of imperfections in the analysis or by the application of notional loads. The imperfections considered in the second-order analysis are compatible with the first buckling mode shape and in the order of 0.002.

Notional loads may be applied as lateral loads at all nodes to represent the geometric imperfections. The notional loads shall be additive to other loads and the magnitude of the notional loads shall be:

$$N_i = 0.002\alpha Y_i \quad (1)$$

where  $\alpha = 1.0$  (for ultimate load design combinations),  $\alpha = 1.6$  (for allowable stress design combinations),  $N_i$  = notional loads applied at ends of member  $i$ ,  $Y_i$  = axial force of member  $i$  from the ultimate load design combination or 1.6 times allowable stress design load combination, as applicable.

As a result of the global stability analyses performed by STATICA, the structural designer of Adnan Menderes Airport new domestic terminal buildings, a global buckling safety factor has been calculated as

$$f_{sbuckling} = 6.85 \quad (2)$$

where  $f_{sbuckling}$  is the ratio of buckling load to the service level gravity loads. The first buckling mode shape of the vaulted roof structural system is given in Figure 3.

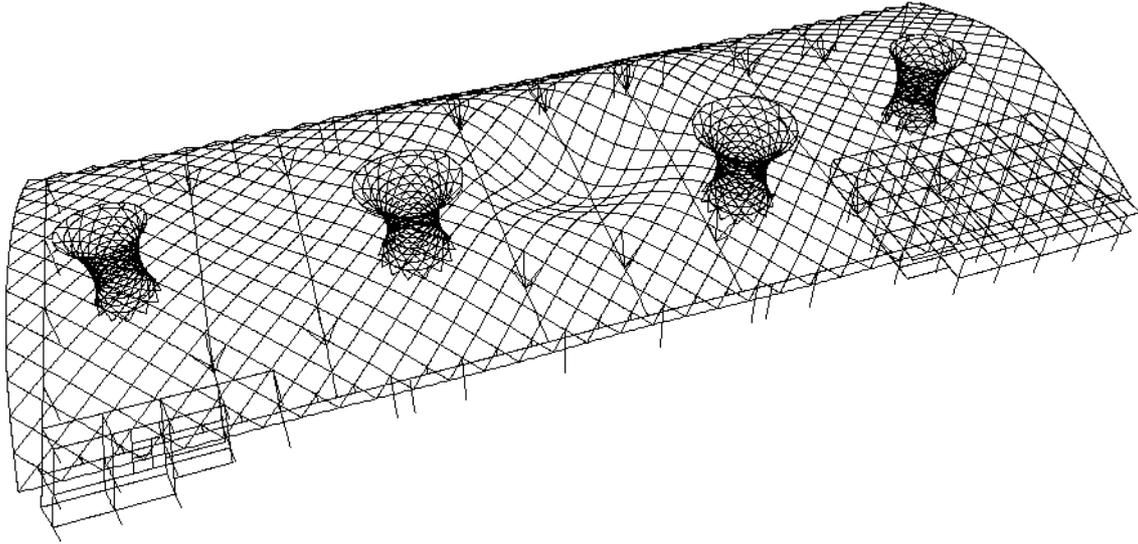


Figure 3. First Buckling Mode of the vaulted structural steel roof system over the departures hall at the Adnan Menderes New Domestic Terminal Building

## VERTICAL SEISMIC EFFECTS

Vertical seismic effects should be taken into account in the seismic design of large-span floor and roof systems. For incorporating the vertical seismic effects, ASCE 7-10 and Eurocode 8.1 provisions embrace different approaches to some extent. In this analysis performed for Adnan Menderes New Domestic Terminal building roof system, vertical seismic effects have been incorporated utilizing a vertical elastic response spectrum obtained by scaling corresponding horizontal accelerations by a factor of two-thirds, in line with the approach adopted in current international codes. First vertical mode of vibration of the roof structure is illustrated in Figures 4 and 5. Seismic effects ( $E$ ) in roof system members is calculated by combination of lateral effects in each orthogonal direction ( $E_x$ ,  $E_y$ ) and vertical seismic effects ( $E_z$ ), per equations given below.

$$E = E_x \pm 0.3E_y \pm 0.3E_z \quad , \quad E = E_x \pm 0.3E_y \pm 0.3E_z \quad , \quad E = E_x \pm 0.3E_y \pm 0.3E_z \quad (3)$$

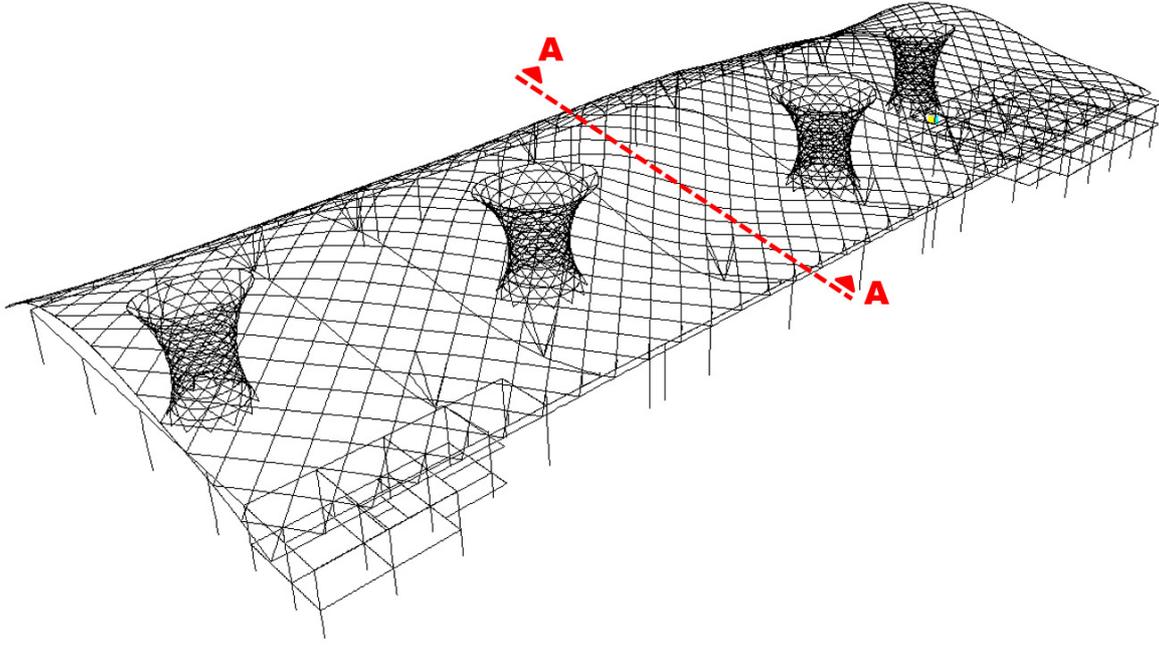


Figure 4. Roof System Vertical Mode of Vibration (Isometric View)



Figure 5. Roof System Vertical Mode of Vibration (Section A-A)

Results of the above-mentioned analyses have been compared with those obtained using the ASCE 7-10 and Eurocode 8.1 approaches. A close correlation has been reached between the design methodology applied and both code approaches.

## CONNECTION SYSTEMS SPANNING SEPERATE BLOCKS

Designers frequently come across connection systems spanning either separate building blocks or parts of a building that behave in a different way above a certain level. In these situations, supports of the bridging system are generally detailed to be fixed on one end and sliding in both orthogonal directions on the other end. The maximum anticipated relative displacement of the sliding support is determined by assuming the two structures are moving in opposite directions and using the absolute sum of displacements. The design rules for members spanning between separate structures are given in the latest version of ASCE Code (ASCE/SEI 7-10). Accordingly, the absolute sum of displacements of the connected blocks, calculated without the use of building importance factors are multiplied by a magnification factor of 1.50. Additionally, displacements calculated due to torsional deformations as well as diaphragm deformations are also considered. Thus, the loss of gravity support due to relative displacements of the connected building blocks and parts is prevented.

The supports of the “origami” shaped structural steel roof system connecting two separate blocks of the domestic terminal building is designed in accordance with these principles as illustrated on Figure 6.

The sliding support at the airside of the span allows for 440mm travel in each direction parallel to the span while in the transverse direction the travel allocation is for 135mm in each direction, Figure 7.

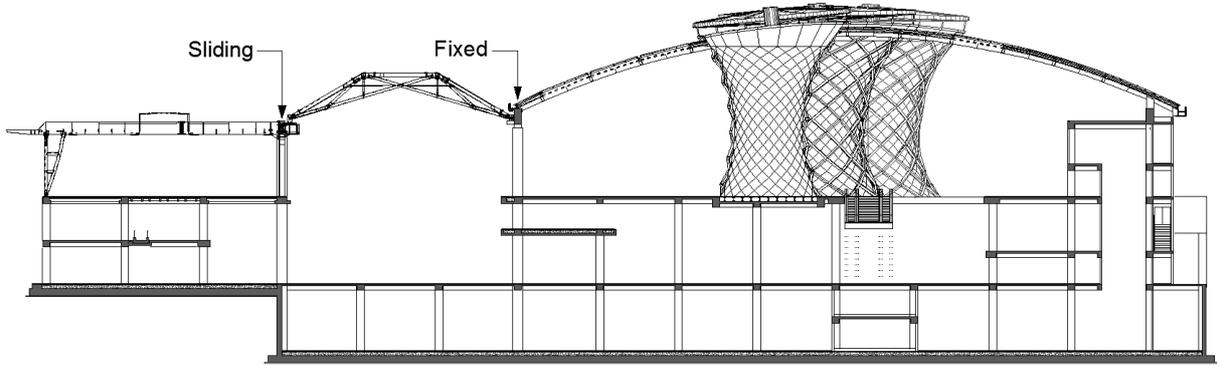


Figure 6. Typical Cross-section of Adnan Menderes New Domestic Terminal Building

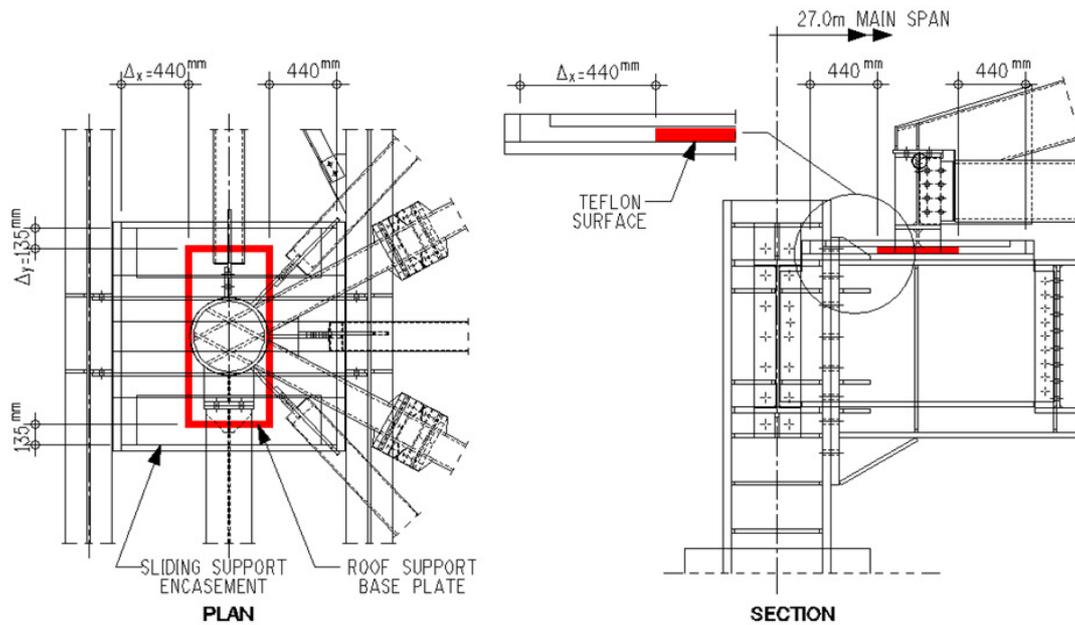


Figure 7. Schematic Sliding Support Detail

## CONCLUSIONS

In this paper, structural design approaches employed by STATICA Engineering Company, in dealing with the special structural design challenges encountered in the design of İzmir Adnan Menderes International Airport New Domestic Terminal are discussed. In this scope, the discussions include the study of global stability of large span barrel vaulted roof structure and vertical seismic response of the

large span roof structure. Finally, the design of structures comprised of blocks with various dynamic characteristics as well as structures that combine these separate blocks.

Findings of this study indicate that structural systems connecting separate buildings or building parts with dissimilar dynamic properties, should be designed with sufficient redundant capability to carry gravity loads. Furthermore, the importance of global stability checks as well as consideration of vertical seismic effects in large span structural systems have been stressed.

It is expected by the authors that, the above mentioned modern approaches will be incorporated into associated Turkish Standards and provisions of the upcoming version of Turkish Seismic Code.

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