Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte
Band: 73/1/73/2 (1995)

Artikel: Tripod column subjected to extreme loading conditions
Autor: El-Metwally, Saiah E.E. / Abdou, Hossam M. / Haddad, Sami
DOI: https://doi.org/10.5169/seals-55358

Tripod Column Subjected to Extreme Loading Conditions

Pilier-trépied soumis à des cas de charge extrêmes

Dreibeinige Stütze unter extremen Belastungszuständen

Salah E.E. EL-METWALLY
Associate Professor
El Mansoura University
El-Mansoura, Egypt

Salah El-Metwally obtained his Ph.D in Structural Engineering from Purdue University in 1986. Since then he has been a faculty member at El-Mansoura University. He joined Dar Al-Handasah Consultants between 1990-92.

Hossam M. ABDOU
Assistant Professor
Zagazig University
Cairo, Egypt

Hossam Abdou obtained his Ph.D. in Structural Engineering from the University of Michigan, Ann Arbor. His research interest is related to the analysis and design of concrete structures. He is a member of ACI committees 343 "Concrete Bridge Design" and 368 "Earthquake Design of Structures".

Sami HADDAD
Partner
Dar Al-Handasah
Cairo, Egypt

Sami Haddad has a B.Sc. and M.Sc. in Structural Engineering. He joined Dar Al-Handasah in 1976 and worked as a structural engineer since then. He is currently the Director of the Structural and Construction Management Department.

SUMMARY

The main frames of a unique shading structure are spaced 50 m apart and span 140 m. The frame rafter is formed by a three-dimensional tubular steel box truss which frames into 70 m high tripod columns. The design requirements led to the consideration of many solutions for the tripod column. In this paper the role of conceptual design in arriving to the most efficient solution for the tripod column is illustrated.

RÉSUMÉ

Les cadres principaux d'une structure destinée à procurer de l'ombre sont espacés de 50 m et ont une portée de 140 m. La poutre de la charpente tridimensionnelle est constituée de tubes d'acier et repose, à 70 m du sol, sur des piliers-trépieds. Les exigences du projet conduisent à plusieurs solutions pour le pilier-trépied. L'article illustre le modèle conçu pour arriver à la solution la plus efficace du pilier-trépied.

ZUSAMMENFASSUNG

Die Hauptrahmen eines einzigartigen Sonnendaches bestehen aus dreidimensionalen Rohrfachwerken mit biegesteifem Anschluss an 70 m hohe dreibeinige Stützen. Die Wahl des Tragsystems wurde durch die Forderung nach minimaler Störung des Verkehrsflusses an und unter dem Sonnendach bestimmt, sollte die Rahmentragwirkung erzeugen und die Gründung vereinfachen. Die Entwurfsbedingungen, wie Tragfähigkeit, Duktilität, Unterhaltsfreundlichkeit, Montageverfahren und Bauzeit, erlaubten mehrere mögliche Lösungen für die Dreibeinstütze. Der Beitrag beschreibt die Rolle des Vorentwurfs bei der Entwicklung der wirtschaftlichsten Lösung.

1. INTRODUCTION

A unique shading structure has been designed to cover a very large space in one of the holy places in the Middle East. For the purpose of shading a teflon coated fiberglass membrane has been used, which has a certain degree of translucency in order to allow for natural illumination. The membrane is reinforced by steel cables which are stretched between the main load bearing space frames which are spaced 50 m apart and span 140 m, Fig. 1. In order to control deflection due to any unusual wind loading the main frame is a rigid structure.

The bearing frame was idealized as a three hinged frame and in order to reduce the moments, and thus to transfer loads mainly through axial forces, a space frame was chosen. The main frame rafter is formed of a three dimensional tubular steel box truss which frames into the 70 m high tripod columns. For stability and for controlled deformations the main frames are connected in the longitudinal direction by means of three trusses every bay.

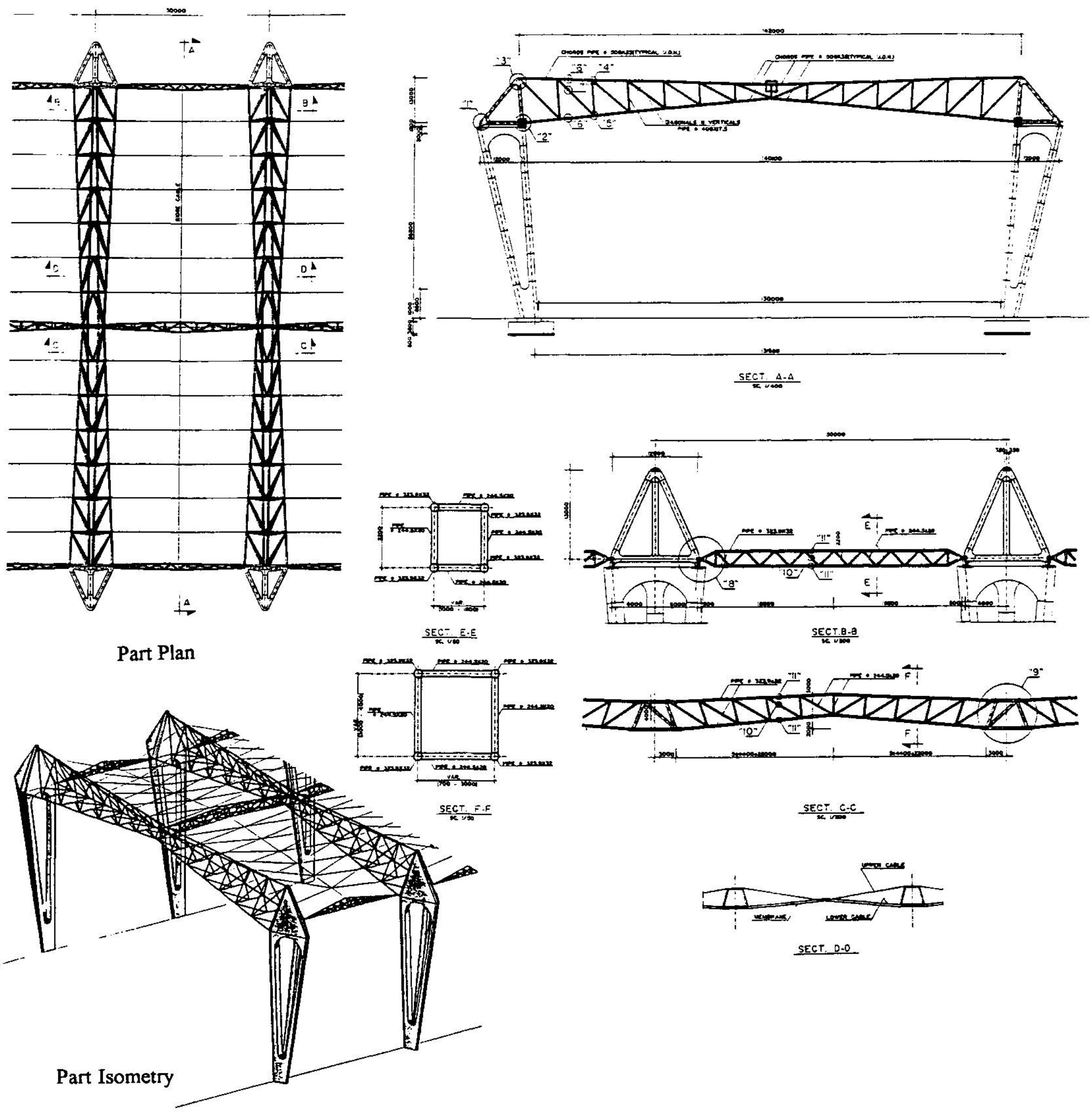

Fig. 1 Shading structure.

The idealization of a structure of such remarkable size and nature represents a great challenge because of its geometry as well as flexibility, very high load magnitudes with their very wide range of variation existed. As a result of structure flexibility a second order analysis had to be adopted during all stages of design.

The choice of the main supporting elements to be tripod columns was based on the need for reducing the interference with the traffic flow around and underneath the shading structure and in order to create the space frame action in addition to simplifying the foundation system. Thus, the foundations of the structure are simple isolated footings.

The large span and spacing between frames will naturally result in forces of very high magnitude. Moreover, the wind magnitude, relatively large compared to the dead and live loads, leads to a very wide range of variation in forces due to its application whether upward or downward. For example, for the outer column the axial force ranges from a small compression to a very high tension (in the order of 1200 ton service). On the other hand, the axial force in inner columns ranged from a small tension to a very high compression (in the order of 1000 ton service).

The significance of the tripod columns dictated the critical consideration of many design factors, such as strength, ductility and maintenance. Also, many construction issues had to be critically considered; for instance, because of time constraints the construction time and hence the construction technique which is also influenced by column height. In order to achieve the design targets different design alternatives were examined and the most suitable two alternatives were either to build the column of precast post-tensioned concrete or to construct a concrete steel composite member.

The two alternatives proposed for column design are presented and a comparison between the two alternatives is drawn. Some unique features of the precast post-tensioned concrete alternative, which seemed to be superior, are discussed.

2. PRESTRESSED CONCRETE SOLUTION

The main reason behind this choice was the high tensile stresses with their range of variation developed in the outer column of the tripod due to load combinations. The wind forces considered in the design were 1.25 kN/m^2 applied to the roof upward and downward and 2.0 kN/m^2 applied to the vertical support. In addition to the load cases due to dead load, live load and wind on the completed structure other load cases were considered such as the load cases during the construction of the tripod as well as during the erection of the main steel trusses, these include the dead weight, wind and construction loads. The structural detailings of the prestressed concrete tripod column are illustrated in Fig. 2.

In order to achieve the highest precision as well as to speed up the construction process the design output was as outlined in the following points.

1. The bottom bulk of the tripod were of cast-in-place concrete. The moments and shears developed due to load combinations at service and during construction at the base are resisted by normal steel reinforcement.

2. The columns of the tripod between the bulk and the top platform consist of 5 precast segments, 8.0 m long each. The prestressing of these columns is anchored in the footing.

3. The prestressing of the outer column of the tripod consist of 18 tendons, of which 12 have 19T15 each while the remaining have 12T15 each. Each of the inner columns have 12 tendons of 12T15 each. For either the outer or the inner columns, 6 tendons 12T15 will be tensioned during the erection of the columns while the remaining tendons will be tensioned after the construction of the tripod column is completed.

4. The segments of the columns will be tied together during construction by means of prestressing

(using the 12T15) and epoxy. The tendons that will not be tensioned until the completion of the tripod column will be coupled between segments; however, not all the tendons will be coupled at the same location. All segments contain about 1.6% normal reinforcement. Each segment has a hole in the middle with a tube attached at the bottom for alignment with lower segments.

5. The columns of the tripod will be braced together during construction by a temporary system at levels multiple of 8.0 m from the top level of the bottom bulk, Fig. 2, to be removed after the placement of the top platform.

6. After the erection of all the straight segments, the precast platform will be placed on the top of the columns and will be anchored to the straight segments with the final prestressing of the tendons. The prestressing at the top of the platform will be anchored to a system of bearing steel plates with brackets which will carry the main steel truss. All the prestressing will be bonded using non-shrink grout except those anchored against the steel bearing plate will be unbonded in the top 2.0 m in the platform region.

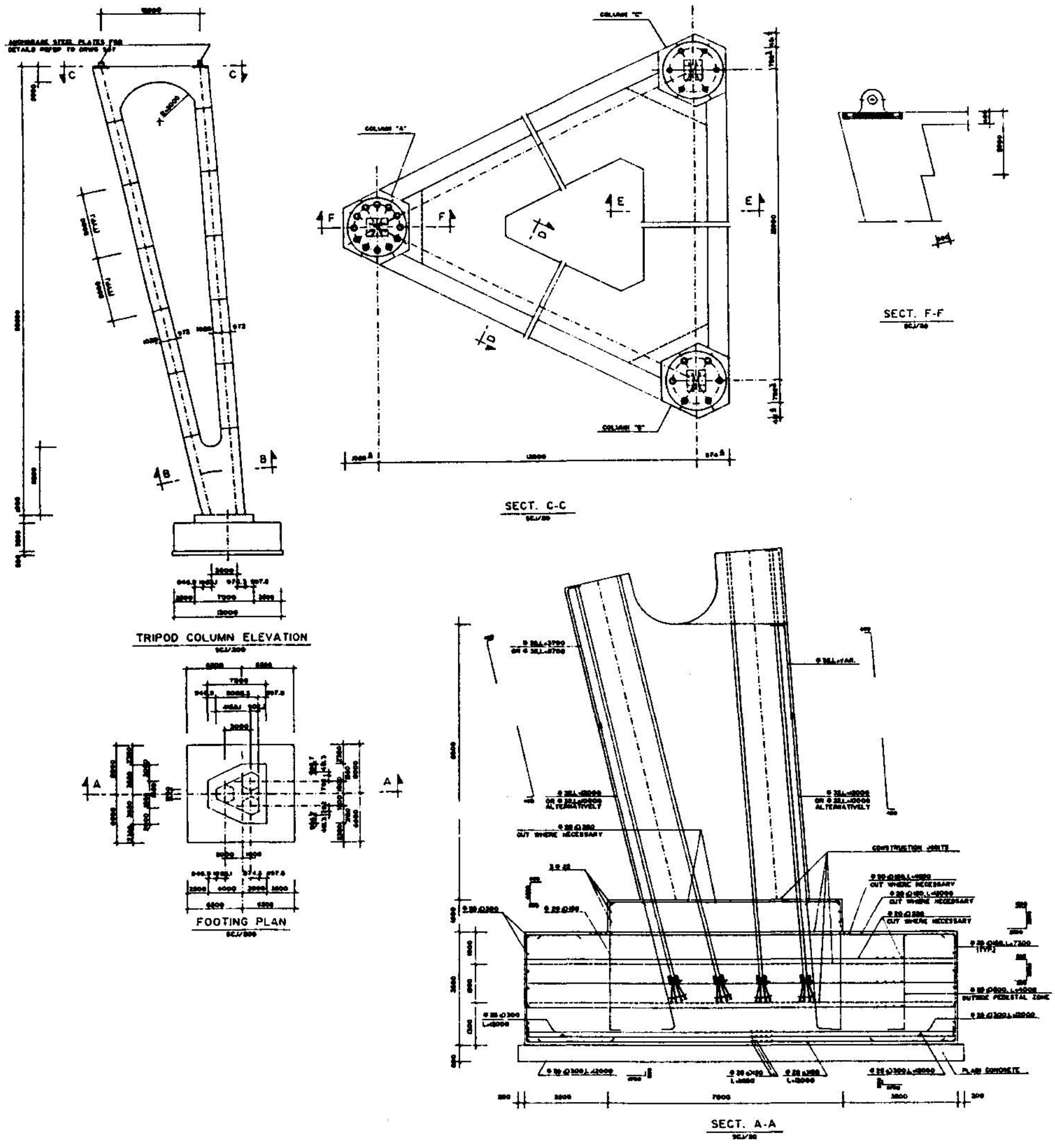

Fig. 2 Prestressed concrete column solution.

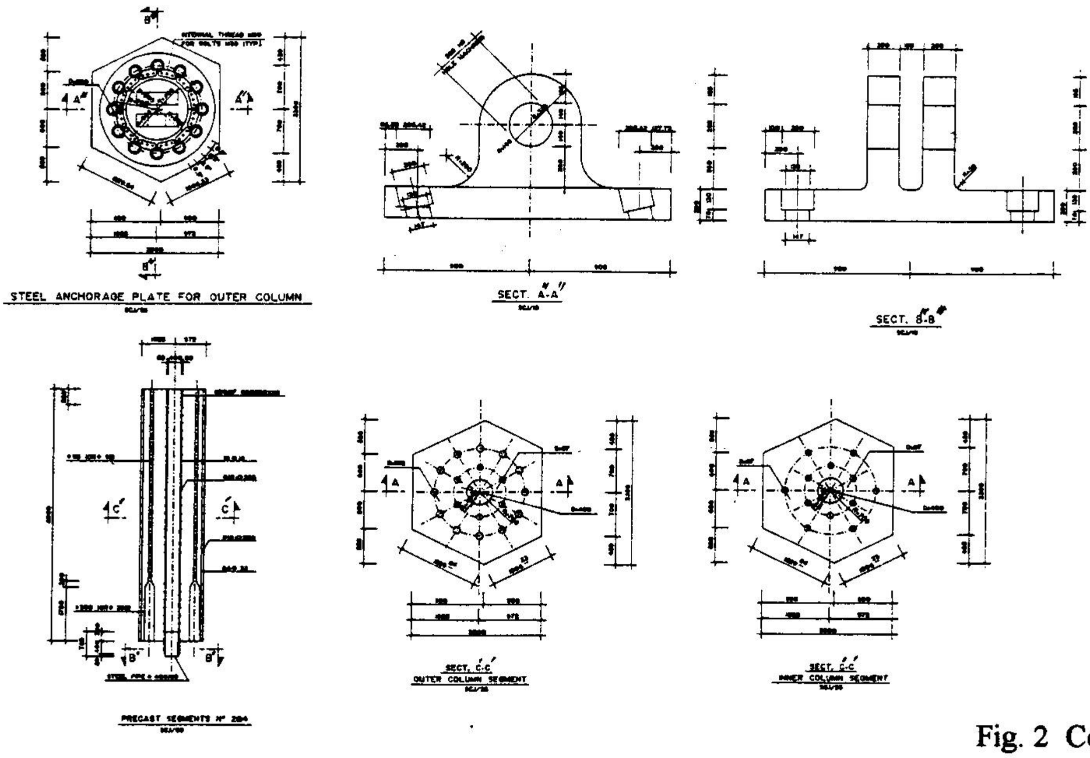

Fig. 2 Cont.

3. CONCRETE STEEL COMPOSITE SOLUTION

In this solution, the tripod column is designed as composite concrete steel members supported on isolated footing. In this type of design, 1100×35 mm steel pipes encased with 300 mm reinforced concrete ring are used; in addition, precast reinforced concrete moulds (cladding) are used as a permanent shutter and also to give the final shape of the column, Fig. 3. The steel pipes will be infilled with lightweight concrete after casting the concrete encasement. The magnitude of wind load and the cases of loading due to construction were the same as in the prestressed concrete solution.

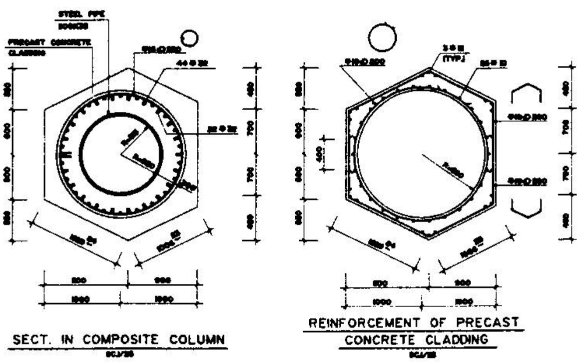

Fig. 3 Composite column solution.

In order to achieve the highest precision as well as to speed up the construction process the design output was as outlined in the following points.

1. The steel pipes will be shipped in sections of about 15.0 m long and welded on site.
2. The steel pipes will be anchor bolted inside the footing.
3. The bottom bulk of the tripod will be made of cast-in-place concrete around the steel tubes.
4. The cladding (concrete moulds of height 4.0 m) will be placed around the steel pipes followed by placement of a circular reinforcing cage between the cladding and the steel pipes. Concrete will then be poured between the steel pipes and the cladding.
5. The bracing of the tripod columns will be as proposed in the prestressed concrete solution.

6. The steel pipes are infilled with concrete after casting the concrete encasing the pipe.
7. The top platform will be cast-in-place reinforced concrete.

4. COMPARISON BETWEEN THE PRESTRESSED AND COMPOSITE ALTERNATIVES

Upon looking carefully at the prestressed and composite design alternatives for the tripod column it can be realized that the prestressed concrete alternative is preferred to the composite alternative. The main arguments for this conclusion are summarized in the following points.

1. Since prestressed concrete experiences mainly compressive stresses normal reinforcement and prestressing steel are protected against environmental conditions; hence, the prestressed tripod columns are more durable. On the other hand, in the composite column the structural steel will be exposed to environmental attack even if encased with concrete because the member will experience both tensile and compressive stresses which will allow for concrete cracking.
2. In the prestressed concrete alternative higher quality control can be achieved since the column segments are precast and on-site casting is eliminated. Moreover, on site welding in the case of the composite solution will be eliminated along with all its requirements of extremely high quality control during welding as well as testing of the welded joints.
3. The prestressed concrete column will require only on-site assembly which will speed up the erection process. As for the composite alternative, on site concrete casting is required in addition to on-site welding which will necessitate longer construction time.

5. CHARACTERISTIC FEATURES OF THE PRESTRESSED CONCRETE SOLUTION

The transfer of loads from the truss into the columns is achieved through the brackets attached to the prestressing bearing plates as illustrated in Fig. 2. This detail transmits the reactions of the truss directly to the prestressing steel in case of tension and to the concrete section in case of compression. In case of tension, additional tensile strain takes place in the prestressing steel while the compression strain in concrete is relieved. In case of compression, the compressive strain in concrete increases while the tensile strain in the prestressing decreases.

The force applied to a column, either tension or compression, as a reaction from the truss, F, is the algebraic difference between the change in forces in the prestressing steel and concrete. As a result of the very large axial stiffness of the concrete section compared to the prestressing steel the change in prestressing force is small. The changes of the force in the column prestressing, ΔP_{sp}, and the column concrete section, ΔP_c, are

$$\Delta P_{sp} = E_{sp}\, A_{sp}\, (F) / (E_{sp}\, A_{sp} + E_c\, A_c)$$

$$\Delta P_c = E_c\, A_c\, (F) / (E_{sp}\, A_{sp} + E_c\, A_c)$$

where E_{sp} and A_{sp} are the elasticity modulus and area of the prestressing steel, respectively, and E_c and A_c are the elasticity modulus and area of the concrete section. In the design of the tripod column legs, the prestressing force is set so that the column is always under compression.

6. CONCLUSION

This paper demonstrates the role of conceptual design in arriving to an optimal solution in structural design. The obtained solution should have the features of robustness and durability and should be easy to construct as well.

ACKNOWLEDGEMENT

The project discussed in this paper has been designed in Dar Al-Handasah Consultants (Shair & Partners)", Dar Cairo, Cairo, Egypt.