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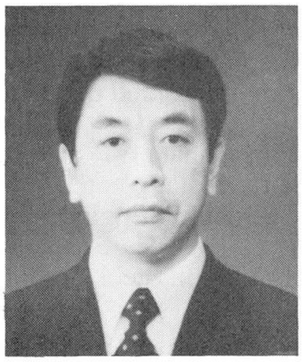
Structural Design and Construction of the Wins Garden Plaza





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Summary

The Wins Garden Plaza represents a pioneer building in urban waterfront development in Kyushu. This facility is composed of the Wins building, which functions as a communitiy place and the garden plaza, which provides a place of interchange for citizens. The site is located on the Dokai Bay, and the plan was designed especially with the sea and waterfront in mind. The large roof of the Garden Plaza is intended to convey a feeling of lightness, and is shaped to somewhat resemble the wings of a seagull (Fig.1). The design of the Garden Plaza has a high decorativeness with the membranes and the structural members in harmony. This report describes the structural design and the construction of the suspension structure for the large roof of the Wins Garden Plaza.

1. Structural concept

The roof (88 m x 45 m) has a low-rise form (rise-span ratio: 0.08-0.13), and is composed of eight units 20 m x 20 m each with a column at the center. The center-to-center distance of each column is 20 m and the curvature is in two directions (Fig.2). The structure is composed of the three parts : membrame, columns and beams of nonuniform section and strings. These

Fig.1 Wins Garden Plaza

strings are composed of 64 upper strings (hereinafter referred to as "strings") for supporting dead load and 24 lower strings(hereinafter referred to as "stays") in the peripheral parts for suppressing the deformation under an upward wind load . Tensile forces are introduced in the strings and membrane so that they can resist thrust and wind load. The foundation is directly supported with reinforced concrete piles by the all-casing construction.

- Project :Wins Yahata
- Site: Kyushu,Japan
- Client :Class Media
- Construction schedule : June1996 to July 1997
- Architects, Structural Engineers:TOHATA ARCHITECTS ENGINEERS and Nippon Steel Corporation
- Contractor :Nippon Steel Corporation and Taisei Corporation J.V.

2. Structural plan

1)This is a rational structural system in which a reduction in weight is aimed at by adopting a single-layer structure and a suspension structure. The thrusts of the roof are suppressed by the girders and tensile forces applied to the membrame and strings.

2)The structure is composed of columns(C1-3), which are members of nonuniform section composed of square sections, girders (G) of nonuniform section, which are composed of square sections with a depth of 470 mm at the center and a depth of 740 mm at the ends, and peripheral girders of triangle section that function as tension rings,which are all rigidly jointed(Fig. 3).

3)For the roof supported with eight columns, strings are arranged on the diagonal lines to each corner where maximum displacement occurs under vertical load and stays are arranged at the peripheral girders (S2). In order to suppress displacement of strings under additional load, tensile forces of 98-108 KN and tensile forces of 19.6-58.8 KN are introduced in each strings and stays, respectively. In consideration of safety, two groups of strings or stays are used as one set.

2.1 Design Load

1)Dead load: DL = 1.47 KN / m^2
(membrane: 0.0147 KN / m^2, surrounding glass sash: 0.294 KN / m^2)
2) Temperature load: 15° C
3) Snow load: 0.65 KN / m^2
For the snow load, total load and half load were considered.
4) Wind load (Coefficient of wind load)

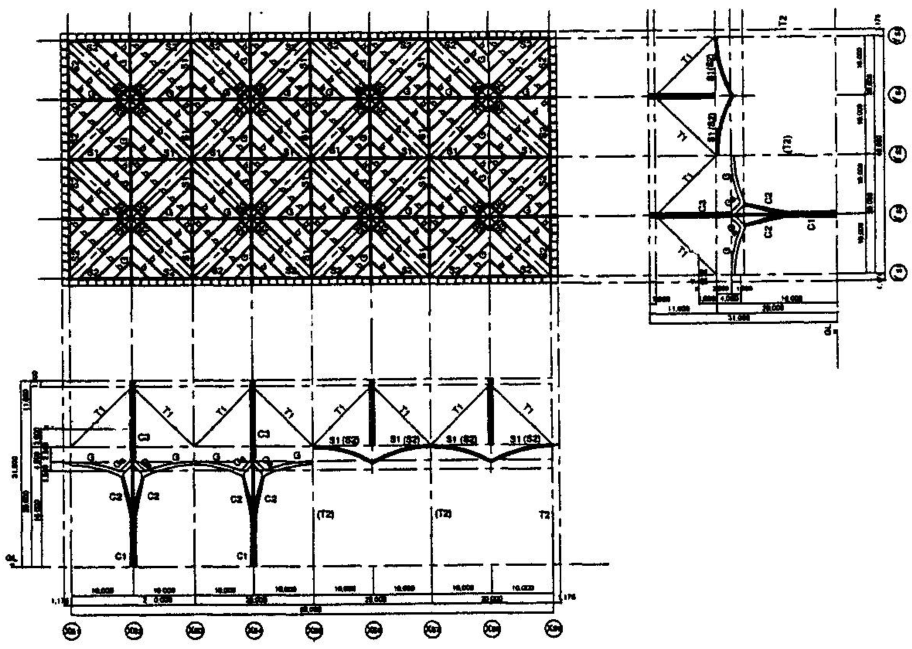


Fig.2 Plan and Section

· General part of the roof in X direction: -0.7
· Eaves part of the roof in X direction: +0.65, +0.6
· General part of the roof in Y direction: -0.7
· Eaves part of the roof in Y direction: -1.3, +0.6
Note (- : upward wind, + : downward wind)

5) Earthquake load
Lateral seismic coefficient k = 0.24 (Co = 0.3, regional coefficient = 0.8)

2.2 Structural Materials

1) Membrane: Glass fiber of ethylene tetrafluoride resin (Type A membrane)
2) String and stay
• Tie rod: 2 ϕ 38, SS490 • Pin: SS490
(Yield point: 275 N/mm^2 and more, tensile strength: 490-610 N/mm^2, elongation 21% and more)
• Turn buckle: S35C • Fork end: SN490B
3) Beam and column: SN490B (string-supporting plates are made of SN490C)

2.3 Strings with height difference

When a uniform load p is applied to a string with a height difference (supposed to be a parabola), the tensile force is affected by sag which is natural deflection by own weight(Fig. 4).
The relation between the sag and the tensile force of string is shown in Fig. 5. The analytical value of the tensile force is almost equal to the roughly-calculated value supposed to be a parabola. The tensile force increases abruptly with decreasing sag. This shows that it is very difficult to keep a string in a straight line condition, and that it is necessary to consider the effect of sag due to natural deflection.

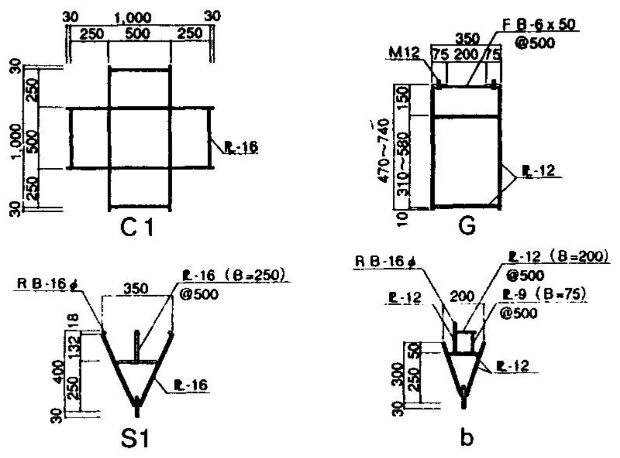


Fig.3 Section

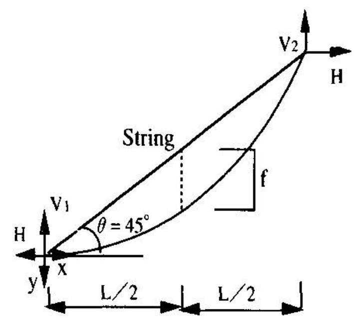


Fig.4 String with a height difference

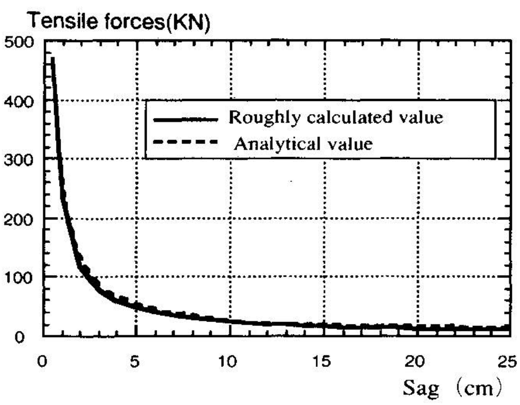


Fig.5 Tensile force and sag of string

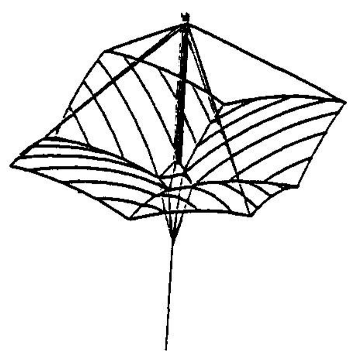


Fig.6 *Single model for preliminary analyses*

2.4 Structural Analysis and Member Design

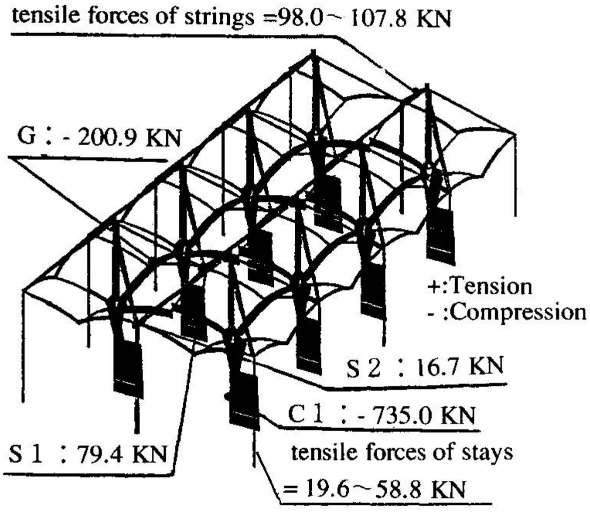
Frames and membrane were separately analyzed by working the reaction force of the membrane to the frames as an external force. As preliminary analyses of a model 20 m x 20 m (Fig. 6), a geometric nonlinear analysis was first conducted using girders and columns as beam elements and strings and stays as cable elements. This analysis is based on the assumption that the cable elements are linear elastic members which only resist tensile forces and that the bending rigidity of strings and stays is neglected. As a result of this preliminary analysis, it was found that the ratio of tensile forces of string is about 30% of dead load. The tensile force working on strings, which shows nonlinear property, was set in consideration of the natural deflection due to the own weight of the string.
The tensile forces of strings and stays were set in truss elements in an overall model, owing to the limited calculation processing capacity and determined by repeated simulations so that the tensile forces of strings and stays and the rigidity of frames are well-balanced (tensile forces of strings: 98 -108 KN). The axial force and deformation under dead load are respectively shown in Fig.7 . The girder (G) at the center functions as a compression ring and the frames and strings of the roof acquire self-balance. In addition, owing to the tensile forces (19.6-58.8 KN) introduced in the stays, the tensile forces of strings finally does not disappear under wind load.

3. Behavior under construction

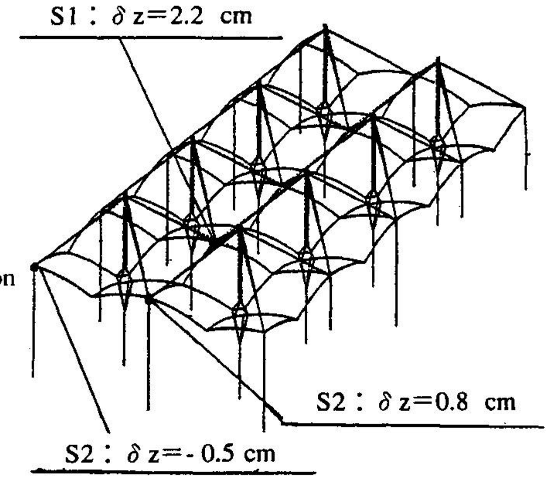
The construction site of this structure is near a wharf and has a marine transportation to the fabrication shop (Wakamatsu Fabrication Center of Nippon Steel Corporation), thus providing adequate conditions. Therefore, the large block construction was accomplished in the fabrication shop, lateral movement was accomplished using dollies which are used to move and install large structures,and marine transportation by barge, and jacking down were carried out by dollies (Fig.8). The adoption of these processes resulted in a shortened construction schedule, reduced site welding, minimized welding strain, etc. The behaviors of stress, displacement and reaction force during construction were examined by conducting analyses because the form of the structure changes from the fabrication stage to the construction stage.

3.1 Fabrication of large block

In the large block process, the structure is assembled in the fabrication stage, lifted with two 650-t crawler cranes, and then set on columns which are assembled beforehand. After that, the structure is welded at the junctions of girder and column. The structure was divided into two blocks, owing to the limited turning space of the dolly at the site. Each block was lifted at four points near the positions of the columns of each block.



a) Axial force(KN)



b) Displacement (cm)

Fig.7 Axial force and displacement under vertical load

3.2 Marine transportation by barge

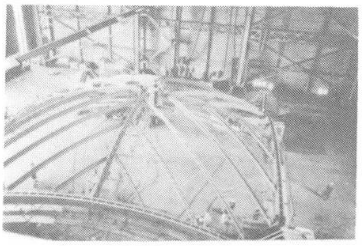
In the marine transportation by barge, block 1 (2548 KN) and block 2 (2940 KN) are jacked up by dollies. These two blocks rolled on Wakamatsu Fabrication Center by barge, and rolled off Yahata higashida port (Fig. 9). To obtain the supporting points of each block to dollies and the required degree of fixing of base of column, temporary truss were installed around the column. Furthermore, wire ropes were installed on each column on the diagonal lines in order to prevent overturns, thus ensuring safety during fabrication and construction.

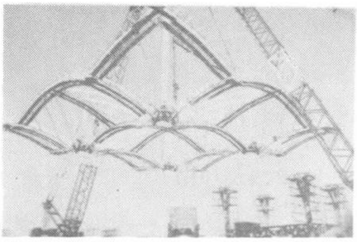
3.3 Jacking-down

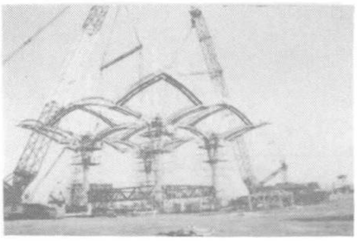
After lateral moving by dollies on site, jacking-down was conducted using individual hydraulic jacks installed beforehand in the dollies at the supporting points (4 points) of temporary truss. Each block of structure was set so that the displacement of the bottom end of the column was 5 mm or less, because the supporting positions of temporary truss are away from the columns. After the completion of jacking-down, junction of each block of structure and the base of column installed beforehand are welded on site. After the concrete of the bases of the columns had obtained the prescribed strength, the temporary truss were then removed.

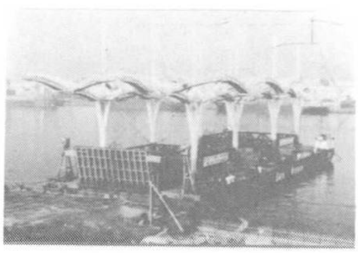
3.4 Tensile Forces

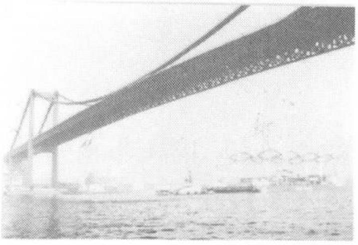
In each unit, the strings in the diagonal direction with the column at the center and the structure are arranged in symmetry. Therefore, the structural property is close to self-balance. Because tensile forces of strings are introduced by the own weight of the structure (Fig.10). Because the strings attached to the peripheral girder (S2) (1, 3, 5, 7, 10 and 12 indicate the order of introduction of tensile force) are affected by loss of tensile forces of adjacent strings, the tensile forces of strings were introduced at the same time from the center

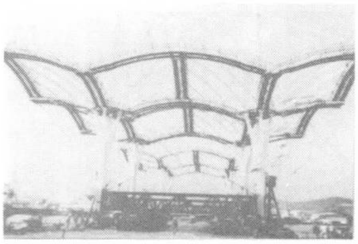

1)Fabrication on plant

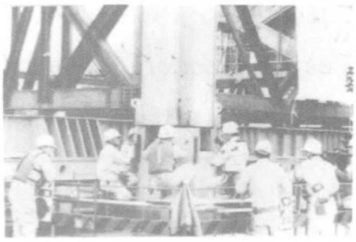

2)Large block fabrication


3)Setting structure on column


4)Rolling on by barge


5) Marine transportation


6)Lateral movement by dollies


7)Jacking down by dollies

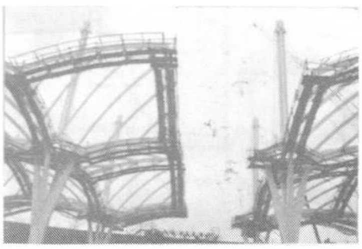

8)Junction of joint

Fig 8 Process of construction

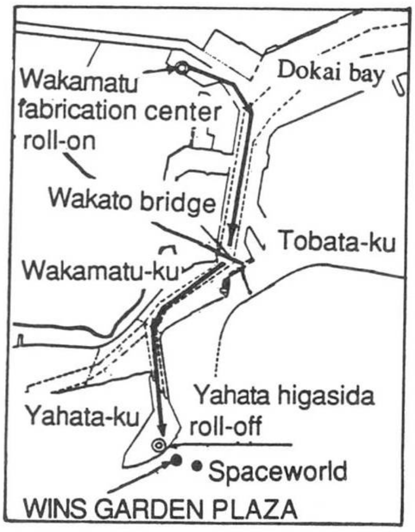


Fig 9 Marine transportation by barge

to the ends.The control of tensile forces of strings and stays was conducted using strain gauges. The tensile forces were set so that the maximum value is 1.3 relative to the design value and the minimum value is 0.9 relative to the design value. The measurements of tensile forces were carried out in six steps: before the jacking-down of each block (Step1), after jacking-down· (Step 2: temporary truss exist), after the welding of the junctions (Step 3: after the removal of temporary truss), and 60%, 80% and 100% of design value (Steps 4 to 6) (Fig.11). For the tensile forces of strings and stays, however, the total of the measured values of two members was adopted. The tensile forces of strings and stays finally met the target values relative to the design values.The change of tensile forces of stays are little compared to that of temperature (Fig.12).

4. Conclusions

This paper described the design and construction of the suspension stucture applied in the large roof of the Wins Garden Plaza. In order to cope with the behavior in each form of this structure from the fabrication to the final stucture, examinations were conducted into the residual stresses due to welding strains, and fabrication procedure were also conducted so as to ensure initial form in addition to the above technical problems. The authors would like to extend their thanks to those persons concerned who gave their cooperation in constructing this structure.

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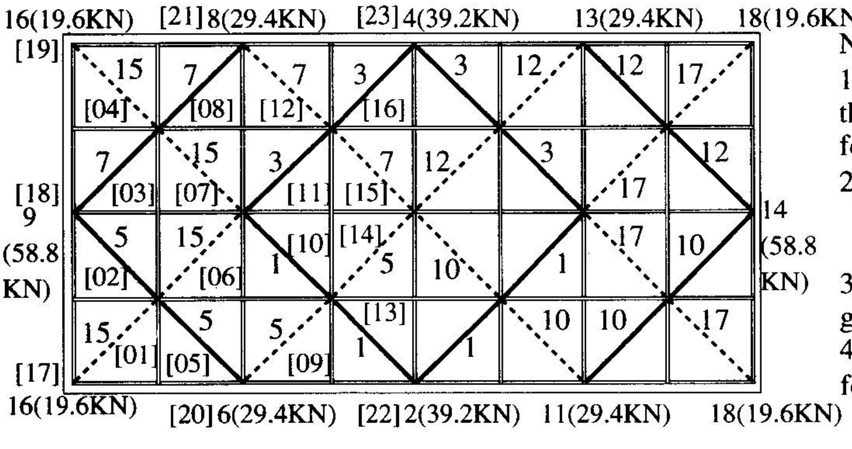


Note
1) Numbers 1 to 18 show the order of tensile forces
2) tensile force
107.8KN: —
98KN: ---
3) [ ] indicates strain gauge number.
4) () indicates tensile forces of stays.

Fig.10 Tensile forces and order of introduction

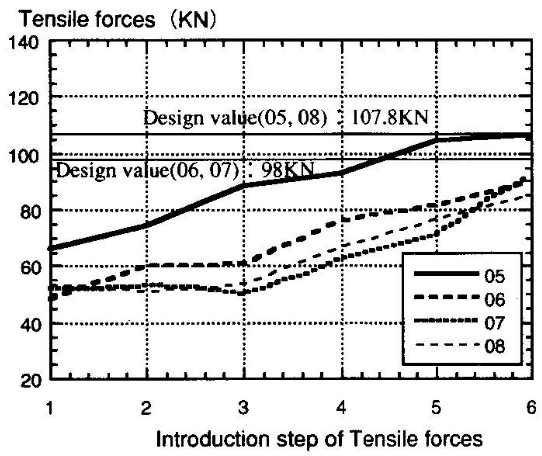
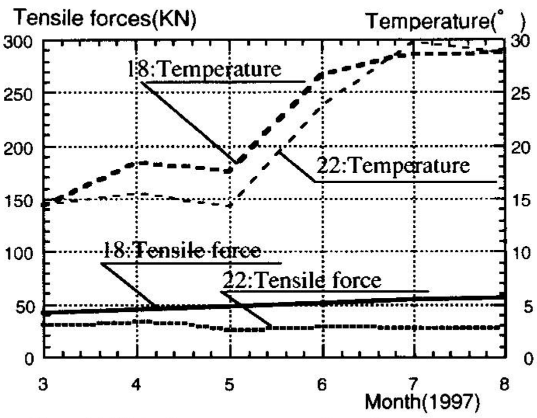


Fig.11 Transition of tensile forces of strings



Note:18,22 indicate gauge number of stay

Fig.12 Transition of tensile forces and temperature of stays