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APPLICATION OF PLANAR MODELLING OF BAR STRUCTURES DURING THE EXAMINATION OF THE SZÉCHENYI CHAIN BRIDGE

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Abstract

Planar modelling of Széchenyi Chain bridge used in association with the load test after the renewal in 1987-88 is presented. The computation was devoted to demonstration of the distribution of the tension forces in the suspension bars. In order to get adequated results, a second order theory was used. It was necessary to take the 'load history' of the bridge into consideration. This effect was evaluated by a 'try-and-error' method.

Keywords: planar bar modelleng, finite element method.

Some more difficult problems of approximating the planar modelling of bar structures are presented here through the analysis of the most wonderful relic of the Hungarian bridge construction, i. e. the Széchenyi Chain Bridge. The planar modelling of bar structures was used in association with the load test during the renewal of the bridge in 1987–88.

The side elevations of the bridge are shown in *Fig. 1.* The double suspension chains running in parallel planes are the most important load-bearig elements of the bridge. The ends of the chains are fixed by special anchorage system in the anchorage chambers built on the Pest side and Buda side embankments. The shoes inserted in the abutments and piers give way to the horizontal motion of the chain bunches. The eye-bar elements of the chain bunches are connected together by the hinged joints. The wagon way and the sidewalks are laid out on a relatively complex floor system. The floor system is supported on stiffening girders of double-intersection quadrangular trussing. The cross-girders are clamped in the stiffening girders on which the longitudinal girders are supported. The reinforced concrete floor slab providing the road surface for traffic is supported on the longitudinal girders. The three independent beam constructions are supported on the piers and abutments. The beam system is hanging from the hinged joints of the chain bunches with the help of double hangers. The hangers are connected to the beam system by specially constructed adjustable rockers.

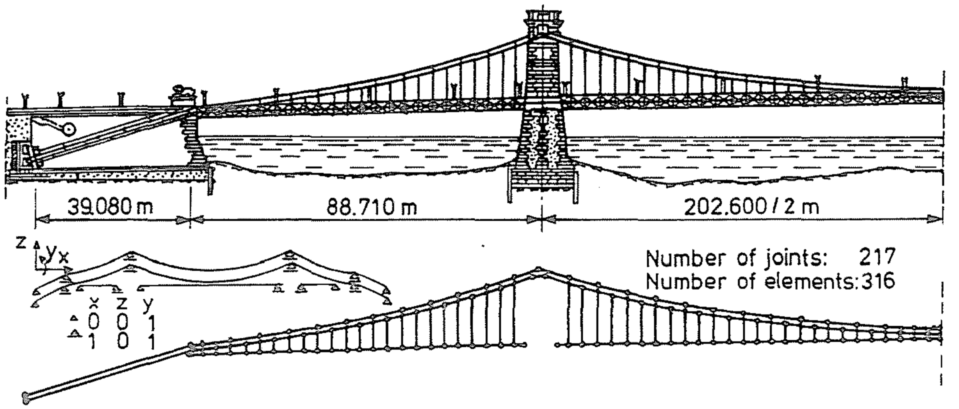

Fig. 1.

The brief structural analysis described above is indispensable for building up a relatively correct model of the bridge structure. From the very start of the model building we have to reckon with the availability of the software and hardware developments. The decisive question is whether the planar model can give a correct answer to the question associated with the behaviour of the structure. Consequently, first of all, the following questions should be formulated:

1. what is the ratio of the dead load to the service load like with respect to their effect exerted on the major structural parts (chains, hangers and beams),
2. what is the distribution of the service load like in the hangers,
3. what deformation can be expected by the effect of the service load.

Since the beams are relatively narrow, it would be pointless to calculate the bridge structure for lateral torsion. Therefore, it is sufficient to take into consideration only the load perpendicular to the longitudinal axis of the bridge. In this case, there is no reason for choosing a spatial model. It should be noted that at the time of performing the calculations presented here (1987), the analysis of a spatial model would have involved difficulties to overcome hardly in software–hardware conditions. In this way, the first decision for model building was made.

The following question was how complex the model of the beam structures should be. With the knowledge of the beam structures, the following models were formulated:

a) truss model (each chord and truss member representing a separate element) with the complex holding from the part of the other elements of the beam structure,
b) truss model with the neglection of the complex holding of the beam structure,
c) beam model subject to bending and shear replacing the beam structure.

The above possibilities were considered in succession. The formulation of model a) would have involved an immense amount of work. At the same time, the result would be doubtful due to the uncertainty of the actual complex holding. Solution b) would have been possible, however, the number of elements and joints, i. e. the size of the model would have run into difficulty with respect to the hardware conditions, on the one hand, and it would have required a considerable preliminary work, on the other hand. Model c) involves the reckoning with the trussed beam by a beam subject to bending and shear as having substituting properties and involves the restriction of the analysis results to the truss model.

On the basis of the above train of thoughts, solution c) was accepted. The planar model of the bridge structure was determined as shown in *Fig. 1.* The model contains 316 elements and 220 joints. The co-ordinates of the joints were assumed on the basis of the general plan drafted in 1949. The geometric data of the chain bunches, hangers and trusses were provided by the surveys. The chain and hanger elements in the model of the bridge structure are two-hinged truss members. This condition can be ensured in two ways:

a) a momental hinge is assigned to both ends of each element involved,
b) the flexural rigidity of each element involved is defined as zero.

Both procedures will have the consequence that the rigidity of rotation (angular displacement) of the joints interpreted along the catenary will be zero. As a result of this, certain elements in the main diagonal of the rigidity matrix are of zero value, i. e. the problem cannot be solved mathematically without the modification of the stiffness matrix (the model). The obvious way of the modification is that an adequately rigid, flexible support is assigned to each unstable degree of freedom. This modification is performed automatically by some software, and the user is informed about this operation performed. Naturally, this procedure cannot be related to the elimination of the instability of the entire model (e. g. the elimination of modelling errors).

Great care should be taken when formulatingthe load model of the dead load. This rule should be observed especially when the dead load exerts a considerably greater effect on the individual structural elements than the expected service load does. This is the case with the Chain Bridge. The modelling operation is aggravated by the fact, too, that the known initial geometry is related to the structure loaded with dead load. Additional difficulty is involved by the fact that the distribution of the dead load effect depends on the assemblage history of the structure. The assemblage history of many built structures was not recorded, and due to it, it would fall into oblivion later on. In these cases, the correct finite element analysis either will be renounced, or certain assumptions will be made and the fact be realized that the behaviour of the structure can only be rendered probable from the series of parametric solutions.

In the case of the Chain Bridge, the mentioned difficulty was eliminated by adjusting the dead load distribution of the floor slab (the forces arisen in the hangers) during the reconstruction of the bridge. As a consequence, a tensile force of about 200 kN can be probably estimated in each couple of the hangers.

After all, the following procedure was applied when modelling the dead load:

1. the dead load of the chain bunches was reduced into the joints of chains,
2. the sort of load distribution acting along the substituting beam and inducing a tensile force of about 200 kN in each hanger was found by iteration.

We started from the dead load formulated by means of the above procedure, and, in turn, that was considered an external load.

It was already mentioned before that the known 'initial' geometry was in force only for the model loaded by dead load. Therefore, the initial geometry had to be modified so that by the effect of the substituting dead load, the model should resume its original formulation. The essential concept of the iterative procedure was visualized on a two-support beam in *Fig. 2*.

The procedure contains the following steps:

1. calculation of the deformation caused in the known original model by the effect of dead load,
2. the modification of the known initial geometry by the calculated values of deformation,
3. calculation of the deformation of the modified model,

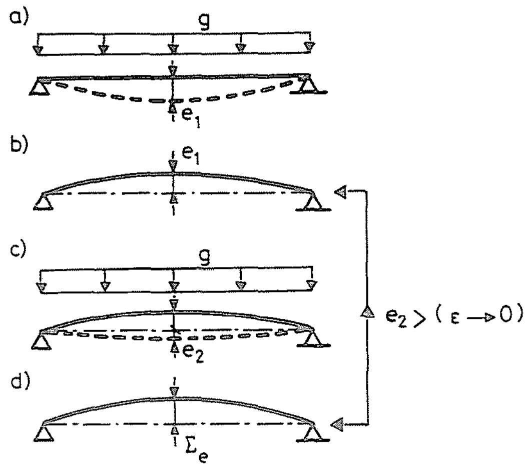

Fig. 2.

4. steps 2 and 3 should be repeated until the shape of the model loaded with the substituting dead load nearly coincides with the known original shape,
5. the latest modified shape should be considered to be the network of the model.

With the knowledge of the substituting dead load and the modified model, the analysis of the effect of service load was performed. The fundamental question is what role the geometrical non-linearity will play here. This question can be generally answered only with the knowledge of linear analysis, or the comparison drawn between the linear and non-linear forms of analysis. In the case of the Chain Bridge, the answer was known in advance. In the state of equilibrium, a relatively considerable force can be found in the chain. In the course of deformation, the angles of deflection of the eye bars are altered, and component forces arise in the direction of the hangers. The complex holding of the structure is realized through the hangers, consequently, it can be stated that the effect of deformation on the behaviour can not be neglected, i. e. a geometrically non-linear analysis should be applied. Due to the geometric non-linearity, the effect of the dead load cannot be superimposed on the effect of the service load. Therefore, the superposition had to be performed already on the level of loading. The effect of the service load was calculated by using the following formula:

$$y_{\text{service}} = y_{\text{dead+service}} - y_{\text{dead}} \, .$$

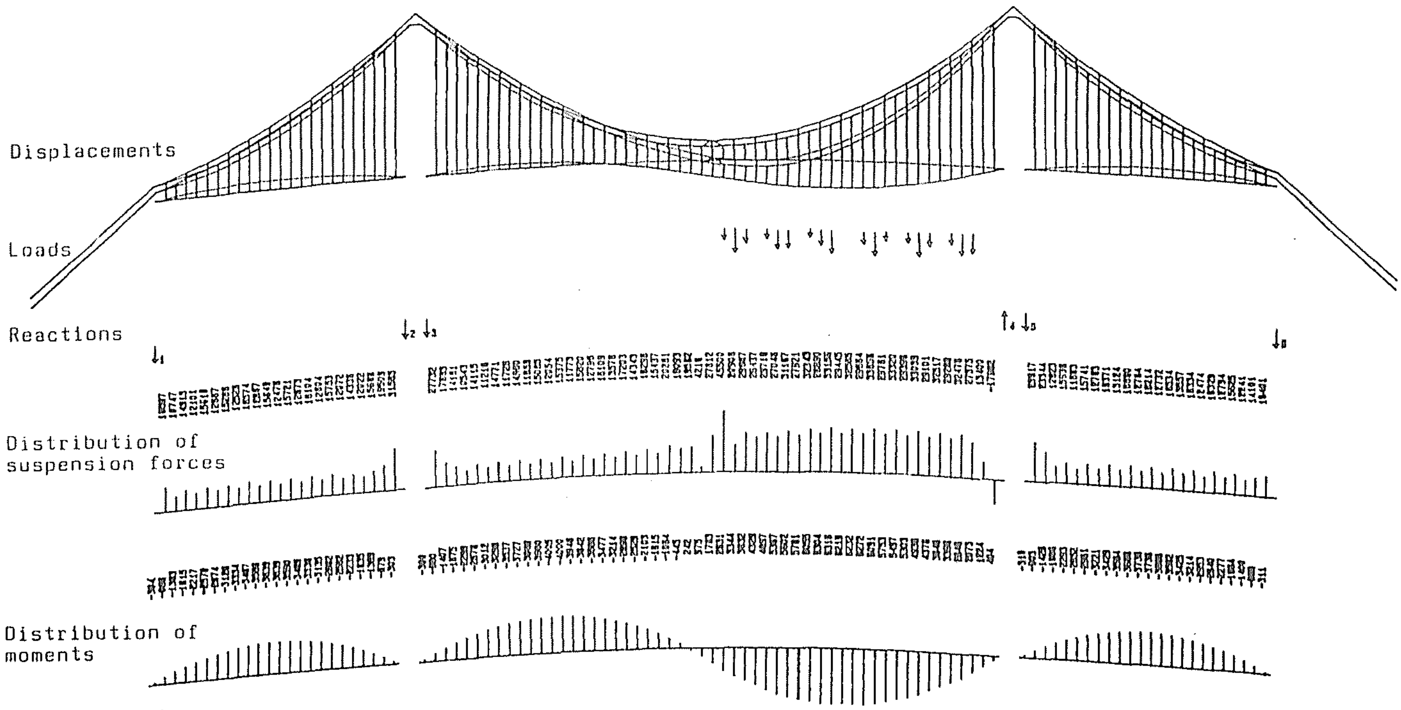

Fig. 3. Széchenyi Chain bridge – Planar modelling

The results of the second-order analysis are shown by graphic representation in *Fig. 3*. The middle beam is loaded by the group of forces only on one side. In the Figure, the deformation of the model, the forces arisen in the hangers and the moments of the beams are represented.

The above calculations were performed with the aim of checking the measurement results obtained in the course of the load test conducted by the Department of Steel Structures at the Technical University of Budapest on the structure of the Széchenyi Chain Bridge. In the course of calculations,

— the distribution of hanger forces,
— the magnitude of chain forces,
— the behaviour of the beams,
— the deformation of the chain and the beams,
— the magnitude of reactions

were examined at different load positions.

Due to the comparison of the results, the static and dynamic correctness of the chosen model was verified with respect at least to the general behaviour of the structure, since the model was not adequate for the determination of the bar forces within the trusses.

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