Discussion

A New Design for Torsion Resistant Suspension Bridges

Paper Presented by HAROLD SAMELSON
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Discussion by **Blair Birdsall**

The author has done a good service in calling attention to the great potential for lateral stiffness of two or more suspension cables hanging parallel to one another, each under the influence of heavy vertical loads. If these cables are considered as chords and they are laced together by web members consisting of diagonal tension members and struts (these struts being perpendicular to the cables), we have what is almost a truss consisting entirely of tension members. The main cables can act as the chords of this lateral truss taking compression or tension, depending on the direction of the applied load. The heavy tension induced in the cables by means of the vertical load which they are supporting gives them the capacity to act as compression members by virtue of reduction of tension.

It is well for the designer to keep in mind this potential for lateral resistance, although it may be only in special circumstances that it would be economical to mobilize this resistance. The lateral web members would require a multiplicity of complicated and expensive details for their connections.

The scheme described in the article is proposed by the author as an alternative to published plans for improvements to the Manhattan Bridge. It is indeed an alternative, but the author has not addressed the subject of whether or not it is a viable alternative. The important questions of economy, aesthetics, and the effect of such a large change in distribution of stresses in the old bridge members would have to be addressed before reaching a conclusion as to the viability of the proposed alternative.

The so-called "braced torsion diaphragm posts", in connection with the outriggers shown in Sects. AA and BB of Fig. 2, represent another means of implementing a long recognized principle of tying the cables to the trusses transversely as a means of producing torsional stiffness in a suspended system. The degree of rigidity appropriate for such a device depends on the details in the particular case. A great deal can be accomplished in this direction by simply tying the cables together with struts and connecting the cables on one side of the bridge with the suspended structure on the other side of the bridge by means of diagonal cables. This scheme provided adequate control as a part of a system applied to the Deer Isle Bridge in Maine to improve its resistance to aerodynamic forces. The scheme was also suggested as a possible alternate for the Manhattan Bridge, with the caution that the effect on the old members of the existing bridge should be carefully studied before such transverse stiffening receives official approval.

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The effectiveness of the author's scheme is clearly demonstrated by the comparative moment diagrams of Fig. 8. The choice of scheme will depend on its cost-benefit ratio as compared with other schemes. For a new structure, any scheme must be compared with a "torsion box" design of the suspended structure, without mobilizing the full potential of the cable for torsional stiffness.

The tie between cable and truss at mid-span is indeed valid and desirable and has a long precedent of successful use.

It is hard to imagine that the torsion posts could provide important torsional resistance and resistance to relative longitudinal movement of truss and cable in the sense indicated in Figs. 11 and 10, respectively. It would appear that the structure necessary to transmit any material amount of shear between cable and truss, particularly at points **BB,** where the torsion posts are relatively long, would become so cumbersome and expensive as to make that function impractical. The necessary strengthening of the existing stiffening truss in the neighborhood of such devices would also seem to be intolerable. It appears to the writer that, if the scheme does prove to be practical in the transverse direction (as seen in Sects. AA and BB), the designer would be well advised to arrange it so that these frames would yield in the longitudinal direction (that is, as seen in "Elevation") so that they would provide little or no resistance to relative motion between cable and truss.

If the Manhattan Bridge problem has served to generate the author's processes of creative thinking, so much the better. Whether or not the scheme is a viable alternative for the Manhattan Bridge, it certainly does give a designer an alternative solution to consider with respect to suspension system design, and the author has performed a service to the profession by making it available for consideration.

Discussion by **Harold Samelson**

The history of the controversy over the proposed design will be reviewed in brief to round out the record.

The consultant's plans for the Manhattan Bridge, which were reported in the October 1974 issue of *Engineering News-Record,* aroused my interest in the development of a constructive alternative. I contacted the consultant, asking him to consider my plan, and received a negative reply. I then submitted a report to the City's Chief Engineer outlining my plans and citing reasons for my opposition to the consultant's proposals. The Chief Engineer sent my report to the consultant's office for their comments, which were returned to the Chief Engineer and then sent to me. In his comments, the consultant stated that my proposal would not work because it lacked the necessary bracing systems required to produce an effective torsional tube. He suggested that the concept be tested mathematically or by model, so that my claims of 87% reduction in torsional displacement could be substantiated. On his suggestion, the concept was tested by three-dimensional computer analyses on two simplified bridge models. One contained the basic elements of a conventionally framed bridge and the other incorporated my proposals. The results confirmed the original estimates made on the basis of crude two-dimensional models.

The original report to the city and the results of the computer analysis formed the basis for a paper published in the AISC *Engineering Journal,* Fourth Quarter, 1976. Another paper dealing with more detailed aspects of the new design and its analysis design is complete and in the consultant's hands for comments.

The discussion submitted by the office of the Manhattan Bridge consultants makes a number of controversial observations, which deserve careful analytical response.

SUMMARY—PRINCIPAL POINTS OF COMMENTARY

A. The consultant acknowledges the fact that the proposed bracing between cables creates a significant source of transverse shear which can be utilized to stabilize the bridge. However, he expresses concern about the complexity and cost of the lateral bracing connections.

B. The viability of the proposed alternative is questioned. The consultant expresses concern for a lack of consideration relating to economy, aesthetics, and stress redistribution associated with the proposed design.

C. Mr. Birdsall compares the action of the torsion post to that produced by a long standing design which ties cables to trusses transversely to produce torsional stiffness of the suspended span. He suggests that a great deal can be accomplished by tying the cables together with struts, and connecting the cables on one side of the bridge with the suspended structure on the other side of the bridge. The success of this design in improving resistance to aerodynamic forces on the Deer Isle Bridge in Maine is cited as evidence of its effectiveness. The consultant had proposed this plan as a possible alternate for the Manhattan Bridge, with the reservation that its effect on old members be carefully studied.

D. Mr. Birdsall questions the ability of the torsion posts, especially the longer ones, to effectively transmit longitudinal shear and torsion between the cables and the trusses. He believes that the structure necessary to transmit these loads would be cumbersome and expensive, making it impractical. He also expresses concern about the need to strengthen the stiffening trusses in the area of the posts, and suggests a reduction of the longitudinal stiffness of the posts to avoid resistance to relative motion between the cable and truss.

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REPLY—PRINCIPAL POINTS OF COMMENTARY

A. Mr. Birdsall is concerned with the complexity and costs of the lateral bracing connections. In my opinion, one of his more promising designs needs such a system. His use of lateral struts between cables and diagonal stays from cables to stiffening trusses requires the design of heavily loaded details. If the diagonal stays are to be effective in distributing heavy eccentric loads, they must transfer these loads to the cables. I do not know whether or not conventional cable bands have the ability to withstand these high loads without slippage. Ironically, my proposal involves cross-bracing between cables connected to the bands and positively anchored to the tower. This is an excellent mechanism for restraining cable band slippage.

B. In Mr. Birdsall's view, the viability of the proposed design should be judged on three factors: economy, stress distribution, and aesthetics. At this time in the long history of attempts to make the bridge function without excessive and costly repair, it is unwise to raise the issue of relative cost of designs. It is more important to measure how well the designs would correct the problems of the bridge. The consultant's plan produces reduction of torsional displacement at the quarter point of the main span of under 60%, while my use of the torsion post produces approximately 90% reduction. To add an historical perspective to the issue of cost for correcting the problems of the bridge, it should be noted that in 1955 the founder of the consultant's office, the late D. B. Steinman, recommended a plan whose cost estimate exceeded $100 million to rid the bridge of its problems. This figure shows how seriously Mr. Steinman viewed the problems of the bridge.

As to large stress redistribution, my design does not alter the dead load distribution of stresses. This is not the case in the consultant's design, which unfortunately requires additional study before it can be used safely. Since the current distribution of stresses resulting from the application of live load is harmful to the bridge, it is necessary to change the manner in which load is distributed. My design accomplishes this by forcing more equal participation of cables and trusses in resisting heavy torsional loads. This relieves the stresses in the stiffening trusses and results in smaller deflections. The transverse frames near the torsion posts would require strengthening to deliver the eccentric moment to the posts. The exterior stiffening trusses would distribute this load to nearby connected and unconnected frames.

Aesthetics is a matter of taste which is best left to architects. My opinion is that the proposed design blends in well with the overall structure.

C. Mr. Birdsall said that the torsional post concept would not work because it lacks some basic components of a torsionally rigid tube, but the torsion post concept has been proven effective by three-dimensional computer analyses. Mr. Birdsall's design lacks two essential ingredients that are part of my design. These are: (a) an upper lateral truss to take the transverse shear created by the eccentric loads and (b) a diaphragm rigid enough to be capable of delivering the transverse shear to a horizontal system without allowing it to be taken by the vertical system. The design of long standing would require a sizeable negative moment prestress of old floor beams, which are already carrying loads never anticipated by the original designers. My design would not require a prestress, since the post is rigidly framed. The bracing design used in the Deer Isle Bridge is probably satisfactory for its use of stiffening the suspension system aerodynamically. However, for the heavy transit loads applied to the Manhattan Bridge, it is not rigid enough to be effective because it depends on the bending of the upper and lower floor beams for its resistance to sway. A study of the effect of diaphragm stiffness on the success of the torsion post design is included in my upcoming paper on this subject.

D. Computer analysis has proven that long torsion posts can transmit longitudinal shear between cables and trusses. The sawtooth moment diaphragm of Fig. 8b, a product of the analysis, demonstrates how effectively the shear transfer reduces girder moments. The moment gradients are due to counteracting post moments induced by the longitudinal post shears.

Mr. Birdsall's concern about the burden and expense of transmitting the loads is puzzling. It is inconsistent to readily accept the tie of the cables to trusses at midspan while questioning the post connections which are subject to the same type and magnitude of loads. My analysis for a heavy live load exceeding 1000 kips, applied over 139 ft centered at the quarter point, produced a maximum post shear of 295 kips. This load can readily be transferred to the cables by a yoke assembly at the top of the post. The yoke would grab the cables over a reasonable length allowing a distributed transfer of shear to the cables.

Mr. Birdsall believes that the stiffening trusses near the post need to be strengthened. I disagree, because the posts reduce the bending of the trusses by forcing roughly equal participation of the loaded and unloaded trusses. This can be seen in Figs. 8a and 8b.

The discussion of this paper has served to stimulate the development of alternate approaches to the problems of stiffening suspension bridges. If the presentation of the pros and cons have helped to advance the state of our knowledge in this important design area, then our efforts have been worthwhile.