Why Beam String Structure (BSS)?

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1. Conceptual Analysis

Beam String Structure (BSS) is a type of large-span hybrid structure, which is composed of upper structural member, lower string as well as struts. In terms of upper structural member, it could be beam, arch or plane truss etc.

There are many practical projects adopting beam string structure, the following cases are Shanghai Pudong International Airport (Fig.1.1) and Niigata Kuzutsuka Middle School Gymnasium (Fig.1.2) respectively.

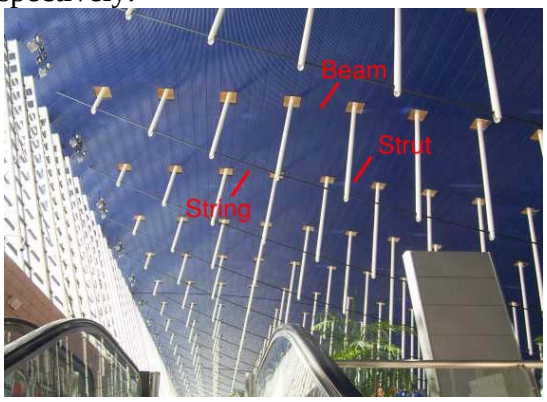

Fig.1.1

Fig.1.2

So, why such a structure is put into use widely in long-span structure, is it better than following the usual practice of constructing a simple beam?

As is known, a simply supported beam carrying a uniformly distributed load has a maximum bending moment at mid-span and the maximum value is proportional to the square of its span, so that it will increase greatly as the result of the augmenting of the span of the beam. When it comes to the displacement, the deflection of a beam is proportional to its span to the power of four and the power of three for uniformly distributed loads and a concentrated load respectively, so if the span of a beam is increased, the displacement will grow considerably. Hence, if such type of beam is introduced in designing of long-span structure, the high inner force and low stiffness of the structure will be the critical problems to be solved. One of the methods is to increase I and A of cross-section, which, however, is uneconomic because what we talk about is large-span structure.

So, what else can we do?

From the basic structural concept, “the smaller the internal force, the stiffer the structure”, the method of reducing the internal force of the beam could be conducted.

What if we use arch beams to replace simple beams (Fig.1.3)?

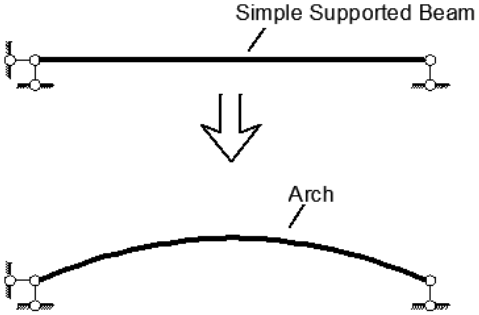

Fig.1.3

While apply vertical loads on the arches, sagging moment (positive moment) will be produced along the whole length of the arch, which is analogous to simply supported beams. Nevertheless, the horizontal thrust at the supports of the arch tends to generate negative moment that could lessen the sagging moment. Consequently, the net moment of the arch is much less than the simply supported beam of the same span under the same kind of loads. Meanwhile, if the material and span of such two types of beams are the same, the cross-section of an arch beam is much less than a simple beam. Therefore, bigger static stiffness would be obtained if the arch beams are used.

However, the horizontal thrust due to the external forces can be quite big, and the supports that provided the thrust should be unyielding and firm enough. So the structure still can be optimized.

What if we adopt string to provide prestress that could supersede the effect of the horizontal thrust (Fig.1.4)?

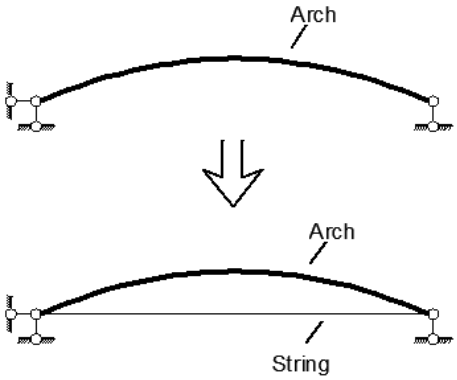

Fig.1.4

Putting steel cable in use to link the ends of the arch, the whole structure becomes self-balanced. The pretention force applied to the string tends to offset the horizontal thrust at the supports and, in the mean time, produces negative moment like the horizontal thrust and induces the deformation of the arch beam to invert arch. Therefore, bigger static stiffness would be achieved if the arch beam and string are combined.

Furthermore, from the basic structural concept, “the most effective ways to increase the stiffness or reduce the deflection of a structure are to reduce spans or to add supports”, the mean of adding supports could be implemented in this case.

What if we introduce struts as the supports of the arch beam (Fig.1.5)?

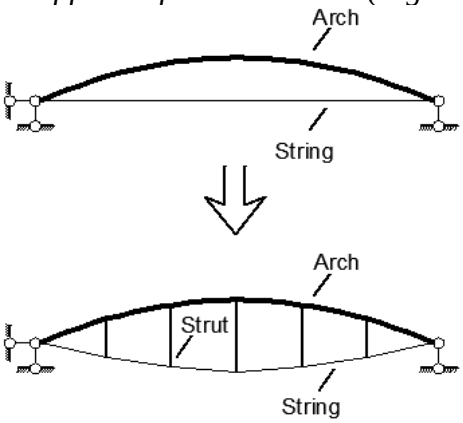

Fig.1.5

In this way, the spans of the arch were effectively diminished and the structure becomes much stiffer as a result. Therefore, bigger static stiffness would be acquired if the arch beams and string as well as

struts are combined. From another point of view, according to the basic concept that, an increase in the depth of a beam could be effective in reducing deflect, we could consider the whole beam string structure as a deep beam, so that such type of beam has a bigger static stiffness than a simple beam.

2. Calculation Analysis

By analysing the moment of a beam string structure, the mechanics characteristic of such structure could be detected.

The bending moment in a simply supported beam carrying a uniformly distributed load (Fig.2.1& Fig.2.2) could be constructed using *structural mechanics solver*.

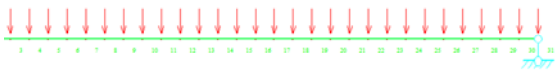

Fig.2.1

Fig.2.2

Considering an arch beam carrying a uniformly distributed load (Fig.2.3), the bending moment at any point of the beam could be calculated, and the bending moment diagram could be constructed as well (Fig.2.4).

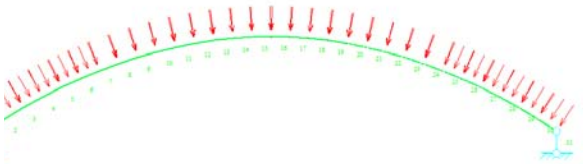

Fig.2.3

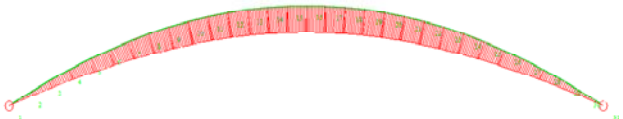

Fig.2.4

The effect of the string and struts of the beam string structure could be considered as concentrated loads that applied at the corresponding section of the beam(Fig.2.5). Similarly, the bending moment that the structure subjected to such form of forces could be constructed as shown in Fig.2.6.

Fig.2.5

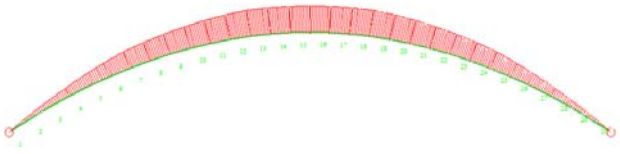

Fig.2.6

If superposing the bending moment of the two states above, the bending moment diagram of a beam string structure is detected (Fig.2.7), and we could easily reach to the conclusion that the bending moment of a beam string structure is much smaller and more distributed than a simple beam.

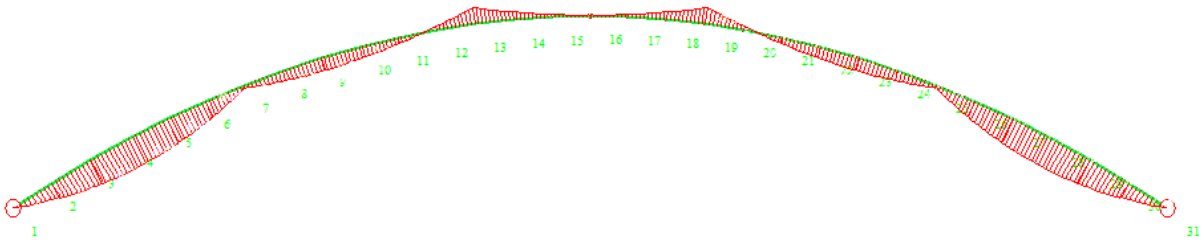

Fig.2.7

3. Model Demonstration

The models of a simple beam and a beam string structure have been made as in Fig.3.1 and Fig. 3.2.

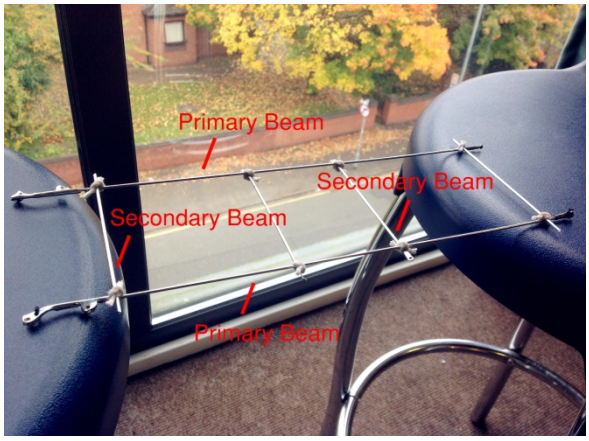

Fig.3.1

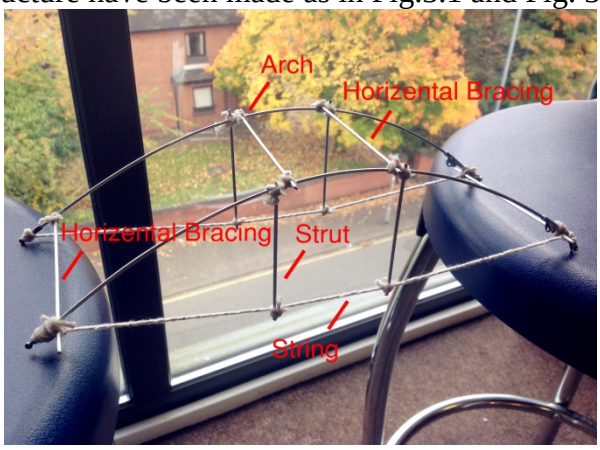

Fig.3.2

The deflection of the two types of beam can be observed by applying loads (adding books) on the structures.

Fig.3.3

Fig.3.4

As we can see from the pictures above (Fig.3.3 & Fig.3.4), the simple supported beam deflected significantly when adding just one book, while the deflection of the beam string structure is not quite obvious even putting 5 books on the structure.

4. Conclusion

The concept and calculation analysis as well as the model demonstration above indicate clearly that, in comparison with the simple beam, the beam string structure is an optimized structure especially when large-span structure is concerned. And the proposing of such type of structure is a great practical application for basic structural concepts.

Reference

1. www.structuralconcepts.org
2. http://www.tokyorope.co.jp/eg/english/beam_string_structure/index.html
3. B.D.Nautiyal, (2001), Introduction to Structural Analysis, New Age International Publishers.