

# A parametric study of the hanger arrangement in arch bridges

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**ABSTRACT:** Steel arch bridge with composite bridge deck with a careful choice of the hangers arrangement represents a good solution with aesthetical and structural advantages for medium spans. Maximum axial forces and maximum force variations in the hangers, maximum bending moment and maximum moment variation in the arch are strongly influenced by hanger arrangement; therefore it is useful to investigate a number of different geometries aiming to give some indications about the configuration that leads to minimum values of these parameters. In this work best arrangements are indicated on the basis of various parameters. The influence of the bridge span, arch rise, load position, configuration and number of the hangers is studied taking also into account in-plane and out-of-plane stability of the arches. Comparisons between network, fan and vertical arrangements of the hangers are shown. Numerical analyses of about 400 configurations are developed.

## 1 INTRODUCTION

Optimal hanger arrangement in steel arch bridges not only lead to minimum values of the axial forces and force variations in the hangers and minimum values of bending moment and moment variation in the arch, allowing to get a good material exploitation, but also it allows to use small cross sections and low weight with aesthetical and structural advantages.

In literature there are more bridges with fan and vertical hangers arrangement than network arch bridges; fan arrangement is generally chosen for aesthetical reasons even if other solutions show better structural behaviour. In this work comparisons between network, fan and vertical arrangements of the hangers, as structural alternative for arch bridges designers, are shown. Some network arch solutions with aesthetical advantages and very good structural behaviour have been designed by Tveit (1987, 2001). Brunn and Schanack (2003) proposed a new hanger arrangement for railway bridges with concrete decks.

In this work different configurations are studied for the case of steel arch bridges with composite deck.

## 2 OPTIMAL HANGER ARRANGEMENT IN ARCH BRIDGES

### 2.1 *Optimal hanger arrangement*

A structure with a commonly defined “optimal layout” presents some important features such as: good safe/durability ratio, cost saving, slim and simple realisation, functionality and aesthetical value. Above mentioned features are basically influenced by control of the minimum and maximum internal forces and moments.

Since bending moments in arches depend on the configuration of the line of thrust and they ought to be reduced in arch bridges, it is necessary to align the line of thrust with the centre line

of the arches. Assuming equal maximum hanger forces, radial resulting forces are obtained if all hangers cross the arch with the same angle and upper hanger nodes are placed equidistantly (see Fig 1).

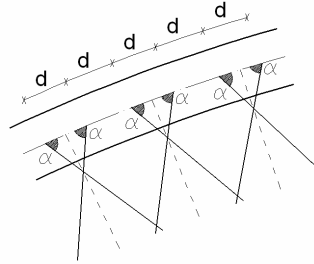


Fig.1. Radial hanger arrangement

From an esthetical point of view, fan arrangement is the most chosen solution; however it leads to higher internal forces and introduces a rotating effect. The case of a tied arch with vertical hangers is well known. The critical section is located at a quarter of the arch span.

## 2.2 Comparisons between hanger arrangements

Optimisation process has been carried out to find an improved hanger arrangement aiming at reducing maximum internal forces (Brunn and Schanack 2003). In a preliminary investigation, two algebraic descriptions, characterized by variable hangers slope and node positions along both the arch and the tied chord, are introduced (see Fig 2 and 3); in a second phase Brunn and Schanack's proposal is considered. In this last configuration all hangers cross the arch with the same angle and the upper nodes are placed equidistantly along the arch. (see Fig. 1).

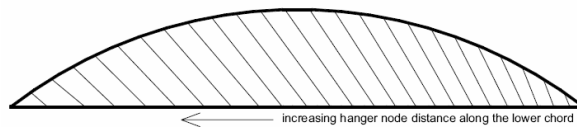


Fig.2. Variation of the lower hanger nodes by the node distances spaced by the help of an ellipse

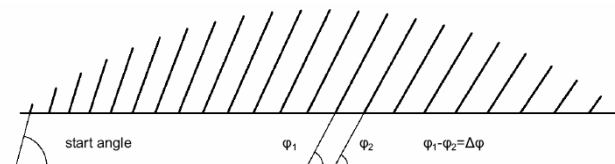


Fig.3. Variation of the lower hanger nodes by the slope of the hangers

All analysis are carried out using the 3D-FEM code Midas Civil considering a distributed load (see Fig. 4).

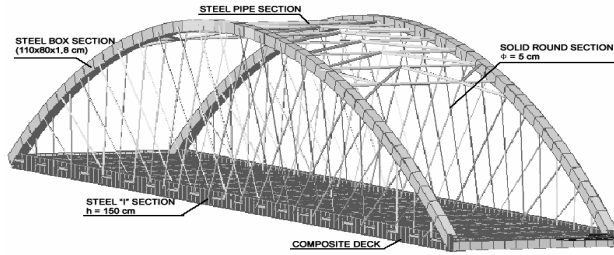


Fig. 4 – 3D-FEM model

Arch bending is minimum when the line of thrust matches as close as possible the arch axis. This result can be obtained if a distributed load acts on the arch radial direction. Even if this load distribution is not extremely accurate, it has been considered as a first approximation for the aim of this work. The applied load takes into account distributed dead and equivalent live loads.

Tab. 1 shows, for the two cases, some relevant results for different parameters: MaxN (maximum hanger force), AveN (average hanger force), ΔN (maximum variation of hanger force), AveΔN (average variation of hanger force); the same notation is used for the arch bending moment.

Brunn and Schanack’s configuration allows lower maximum axial forces while higher values of bending moment can be found in the dispositions similar to fan arrangement, which can be considered to be a particular case of Brunn and Schanack’s proposal for hangers arranged along arch radial directions. In this work many configurations have been developed with fixed hanger upper nodes along the arch and variable hangers angle with respect to the radial directions (one to fifty degrees). An angle between 28° and 37° gives best results in terms of internal forces.

Table 1: Results

		Algebraic descriptions	Brunn and Schanack’s method
MaxN		418.8	356.8
AveN	[KN]	260.0	263.1
ΔN		189.5	162.6
AveΔN		121.5	122.5
MaxM		595.4	609.4
AveM	[KNm]	87.3	174.1
ΔM		282.0	283.9
AveΔM		42.3	74.2

### 3 PARAMETRIC VARIATIONS

#### 3.1 Bridge span

In this analysis thirty models have been developed with spans of 75m, 100m, 150m, 200m and angles of the hangers between 28 and 37 degrees.

Fig. 5 shows similar behaviour for spans of 75m and 100m in which arch bending moment increases with the angles. An opposite behaviour can be observed for 150m and 200m spans.

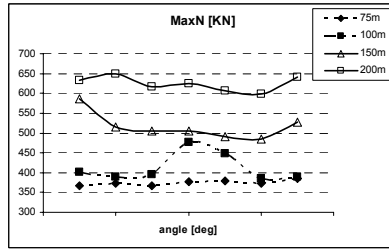


Fig 5 – Bending moment for different spans considered

3.2 Arch rise

In this analysis, bridges with arch rise (h) to span (L) ratio between 0.14 and 0.185 are considered for aesthetical reasons.

Fig. 4 and 5 show that arch bending moment minimum values (Fig. 6) and hanger axial force minimum force (Fig. 7) occur for arch rise minimum values. However, for aesthetical reasons it is suitable to use  $h/L = 0.17$ .

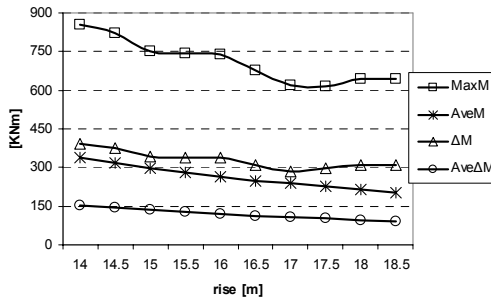


Fig. 6. Bending moment parameters for considered h/L

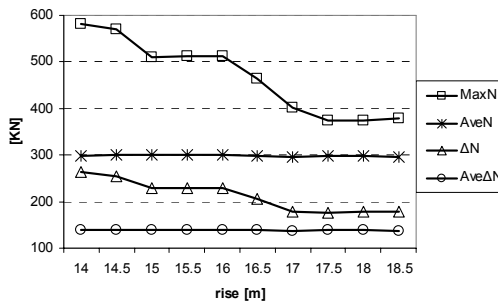


Fig. 7. Axial force parameters for considered h/L

### 3.3 Number of hangers

Bridge behaviour does not significantly change when number of arch hangers increases. Reduction of internal forces due to increasing the number of hangers is not comparable to the consequent increment of the structure cost.

### 3.4 Arch stability

Arch behaviour shows, in-plane and out-of-plane stability problems depending on arch shape, cross-section, restraints, etc. Out-of-plane buckling is critical when no arch bracings are considered. In this section, a comparison between network (with 28°, 30° and 32°), fan and vertical arrangement is developed (see Table 2). Buckling factors show a good behaviour for distributions with inclined hangers that stabilize the plane of the arch.

Table 2: Buckling factors for self weight load condition.

	Stability In-Plane	Stability Out-of-Plane
28°	8.40	2.04
30°	8.37	2.02
32°	8.34	2.01
Vertical	7.67	2.04
Fan	8.06	2.05

### 3.5 Traffic loads on bridge

In this section, other comparisons between network, vertical and fan arrangement are presented.

For the majority of the load conditions, hanger radial arrangement ensures a better distribution of internal forces because all hangers are equally loaded. Small values of bending moment at bridge edges may be obtained in case of vertical hanger distribution when live load is placed near bridge bearings.

Fan hanger arrangement leads to high values of arch bending moment, nevertheless it is often chosen mainly for aesthetical reasons.

Figs. 9, 10 and 11 show arch bending moment's envelope generated by the live load of Fig. 8 moving along the deck for network, vertical and fan arrangements.

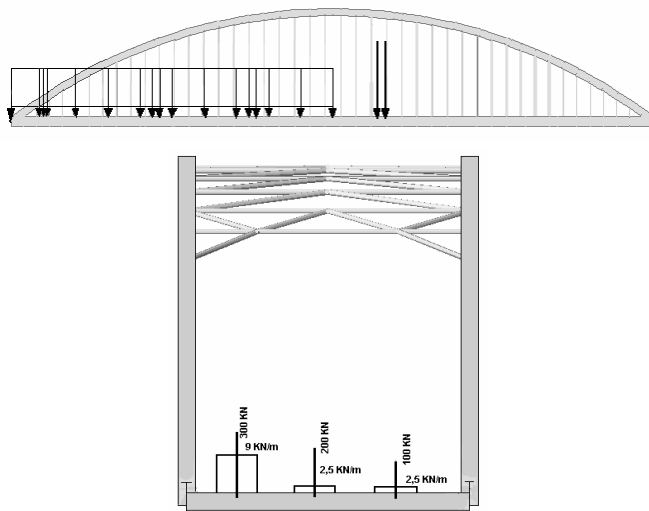


Fig. 8. Traffic live load moving along the bridge deck

The next three figures show that a good distribution of arch bending moment can be obtained for network arch with hangers at the same distance along the arch and slope close to  $30^\circ$  (see Fig. 9).

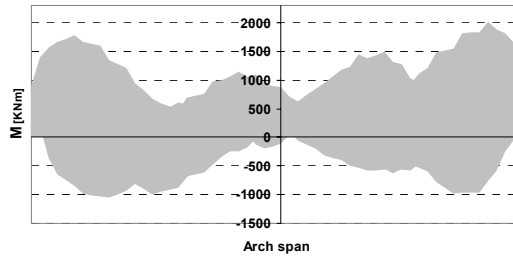


Fig. 9. Arch bending moment envelope for network arch arrangement ( $32^\circ$  crossing angles)

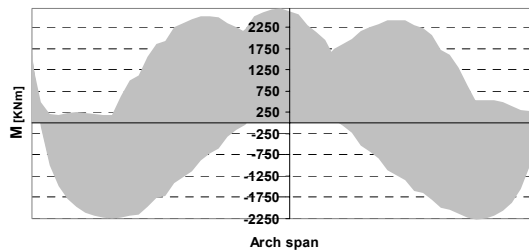


Fig. 10. Arch bending moment envelope for vertical arrangement

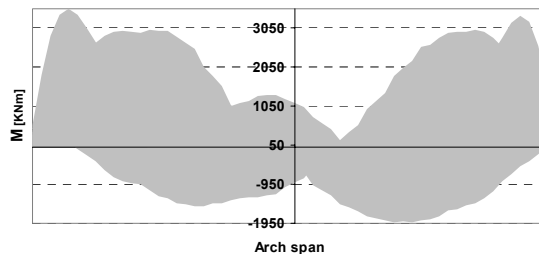


Fig. 11. Arch bending moment envelope for fan arrangement

#### 4 CONCLUSIONS

All mentioned analysis allow some interesting considerations about the different geometrical configurations.

One of the main issues is related to hanger forces; as a matter of fact vertical and fan arrangement lead to the minimum values. On the contrary, the most evident disadvantage of these configurations are the higher values of arch and lower chord bending moments due to low stiffness of the arch plane. This negative effect is not present in network arch bridges due to crossing hangers, which increase the arch plane stiffness.

For network arches with hangers at the same distance, upper nodes along the arch and variable slope between  $1$  and  $50^\circ$ , the minimum values of hanger forces occur in case of low values of slope with respect to fan and vertical configuration.

Hanger arrangement with small inclination with respect to radial direction leads small hanger axial forces but high arch bending moments. The authors suggest that a configuration with  $28^\circ$  angle hanger inclination with upper nodes distributed with the same distances along the circular arch shows a good structural behaviour in case of network steel road arch bridges with composite deck.

#### REFERENCES

- Brunn, B. and Schanack, F. 2003. Calculation of a double track railway network arch bridge applying the european standards, Diploma Thesis, Grimstad, Norway.
- Tveit, P. 1987. Consideration for design of network arches”, *Journal of Structural Engineering* 10, p. 2198-2207.
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