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On the Bearing Capacity of Voussoir Arches

Capacité des charges des arcs maçonnés

Die Tragfähigkeit gemauerter Bogen

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The following investigation of voussoir arches includes arches of stone, brick and concrete without any reinforcement, or when the reinforcement is so insufficient that it will have no influence on the bearing capacity of the structure.

On European roads and railways there exist thousands of masonry arch bridges. The bearing capacity and safety of these bridges is a very important problem which troubles many bridge engineers. In the following paper a description is given of the principles for an investigation of masonry arches and some views on the consequences of the investigation for an improvement of the structure. The method described was used by the author for the investigation of old arch bridges for the Norwegian Public Road Administration.

In Fig. 1 is shown a typical stone arch bridge. The arch and the masonry superstructure is divided by a joint and the superstructure can slip on the arch. The slip, however, is hindered by the existence of frictional forces between superstructure and arch, and the existence of forces in the superstructure. See Figs. 2 and 3.

The forces acting on the arch will be a radial force A and a tangential force T.

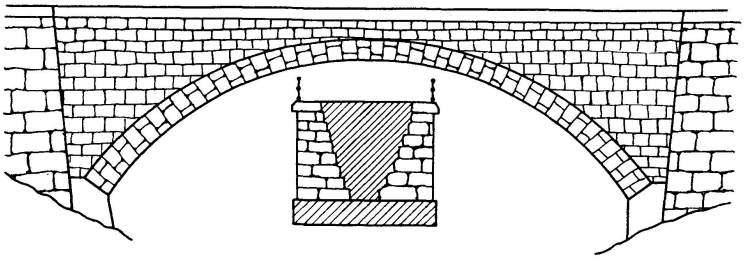

Fig. 1

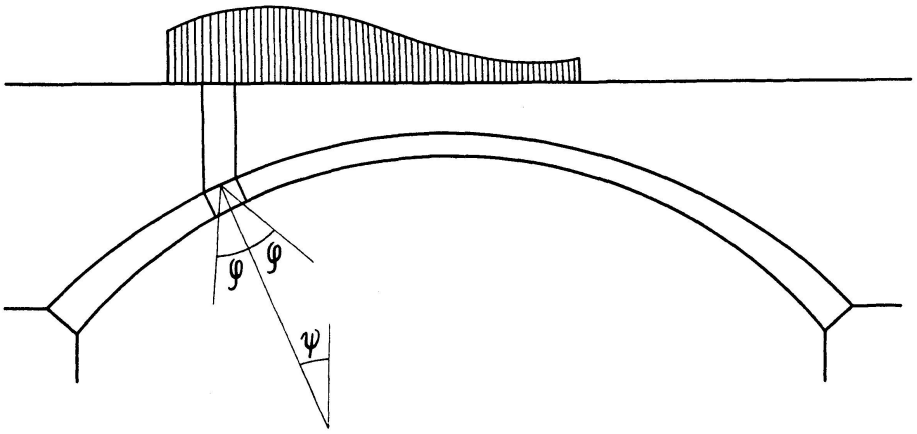

Fig. 2

From Figs. 2 and 3 it can easily be seen that we have the following equation

$$\left|\frac{\Delta T}{\Delta A}\right| \leqq \operatorname{tg}\varphi \tag{1}$$

where φ is the angle of friction between superstructure and arch. The conditions of equilibrium give the following equations:

$$\left.\begin{aligned} \Delta P+\Delta G_s+\Delta V &= \Delta T\sin\psi+\Delta A\cos\psi \\ \Delta S &= \Delta T\cos\psi-\Delta A\sin\psi \end{aligned}\right\} \tag{2}$$

where S and V are the normal and shear forces in the superstructure, see Fig. 3. The superstructure will be a masonry or concrete structure, and is supposed to be cracked and unable to carry any moments. This is an assumption on the safe side, as any moments taken by the superstructure will increase the bearing capacity of the whole structure.

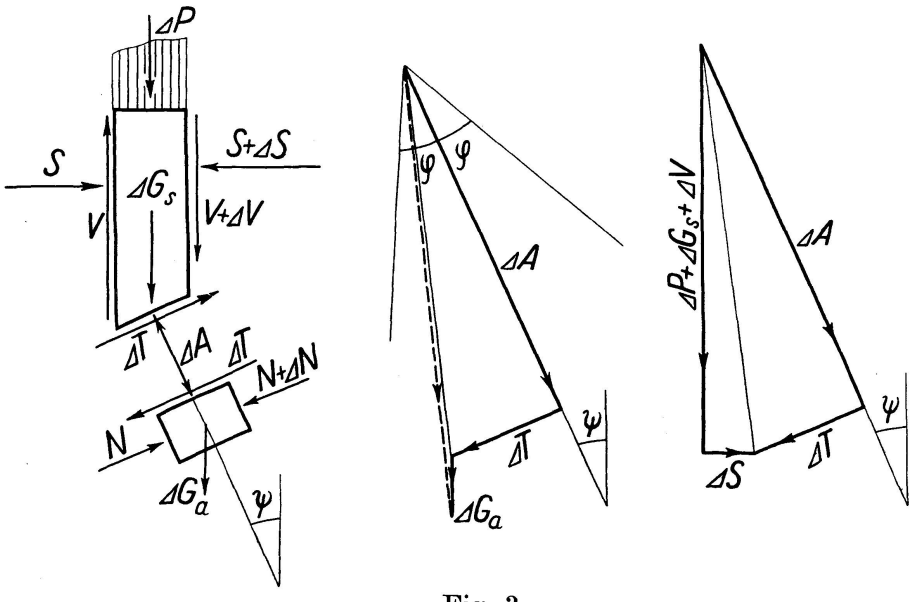

Fig. 3

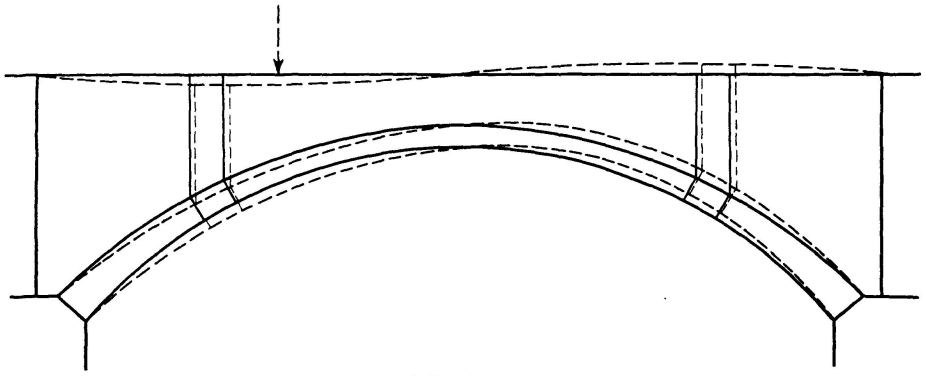

Fig. 4a

Between the forces A and T we have the Equation (1). However, the direction of T is better seen from a sketch of the deformation of the bridge. Figs. 4a and 5a, b show the deformation of an arch if the superstructure would permit any deformations. The displacement of the superstructure is hindered by the forces S and V, and the resulting T and A forces have a direction as shown in Fig. 4b, c. The consequences of the introduction of the forces S and V in the superstructure will be the following:

If it is possible to find forces S and V which will give normal forces N within the arch section, the arch will be stable if the superstructure can transfer the forces S and V to the bridge ends.

The forces S and V are better found by a trial and error method, and it will usually not be necessary to try any new S and V forces if we have found forces S and V which give N forces within the arch section over the entire span.

This gives the following simple first trial:

We assume that the force N follows the middle of the arch for the entire span and find the forces S and V which are necessary for this assumption. If the superstructure is able to transfer these S and V forces, the structure as a whole will be stable and no further investigation is necessary.

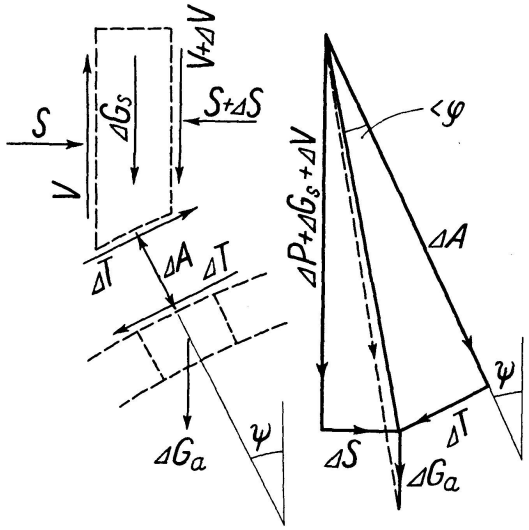

Fig. 4b

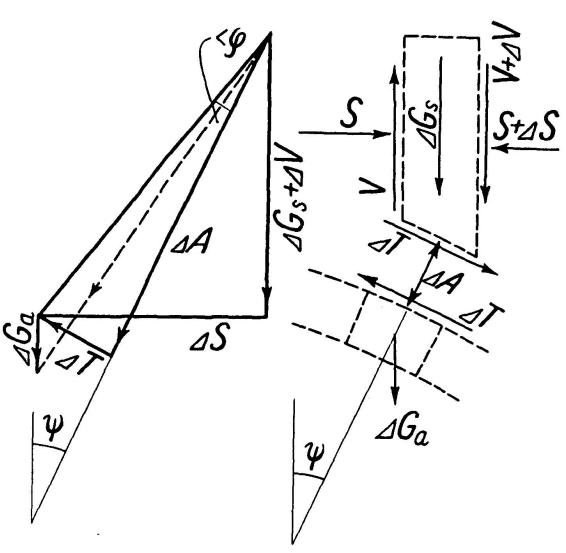

Fig. 4c

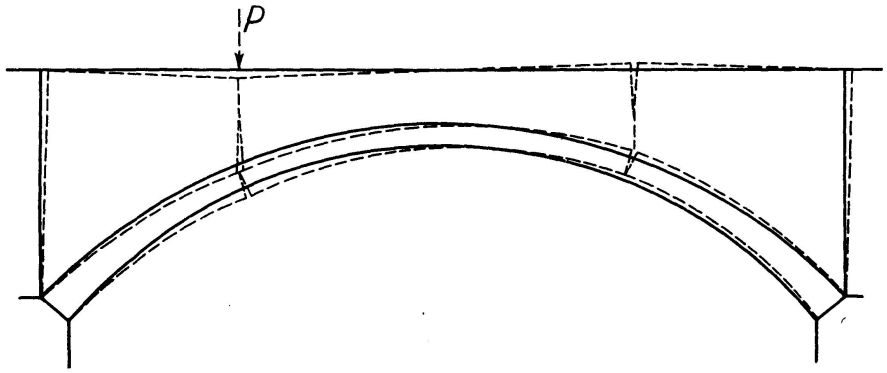

Fig. 5a

The method is demonstrated by an example, Fig. 6 and a graphical solution will be the most convenient one. If the S and V forces given by this first trial will be such that the superstructure is unable to carry them, we have to make a new trial with N forces varying within the arch section.

As will be seen, the superstructure takes an important part in the bearing of loads for arch bridges. The above deduced principle for design will consequently be of minor importance for arch bridges as shown in Fig. 7. This type will give S and V forces only near the centre of the arch.

The increase of the load bearing capacity for arch bridges is very often an important question in handling old bridges. It may be obtained in different manners.

a) Increase of the friction between arch and superstructure.
b) Improvement of the capacity of the superstructure for transfer of forces S and V.
c) Strengthening of the arch.

The methods a and b will usually be the cheapest ones and very often the only necessary repair work will be the injection of cement in the superstructure. Investigation of an arch structure as indicated above, is based on the ultimate bearing capacity of the bridge, and this method may always be used for specially heavy loads or heavy transports which will seldom occur.

If the superstructure consists of a masonry with open joints, the bridge may safely take the investigated load once or several times; however, the

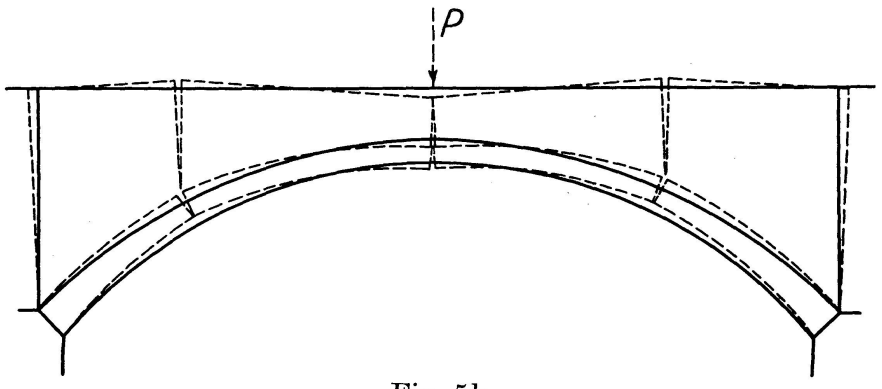

Fig. 5b

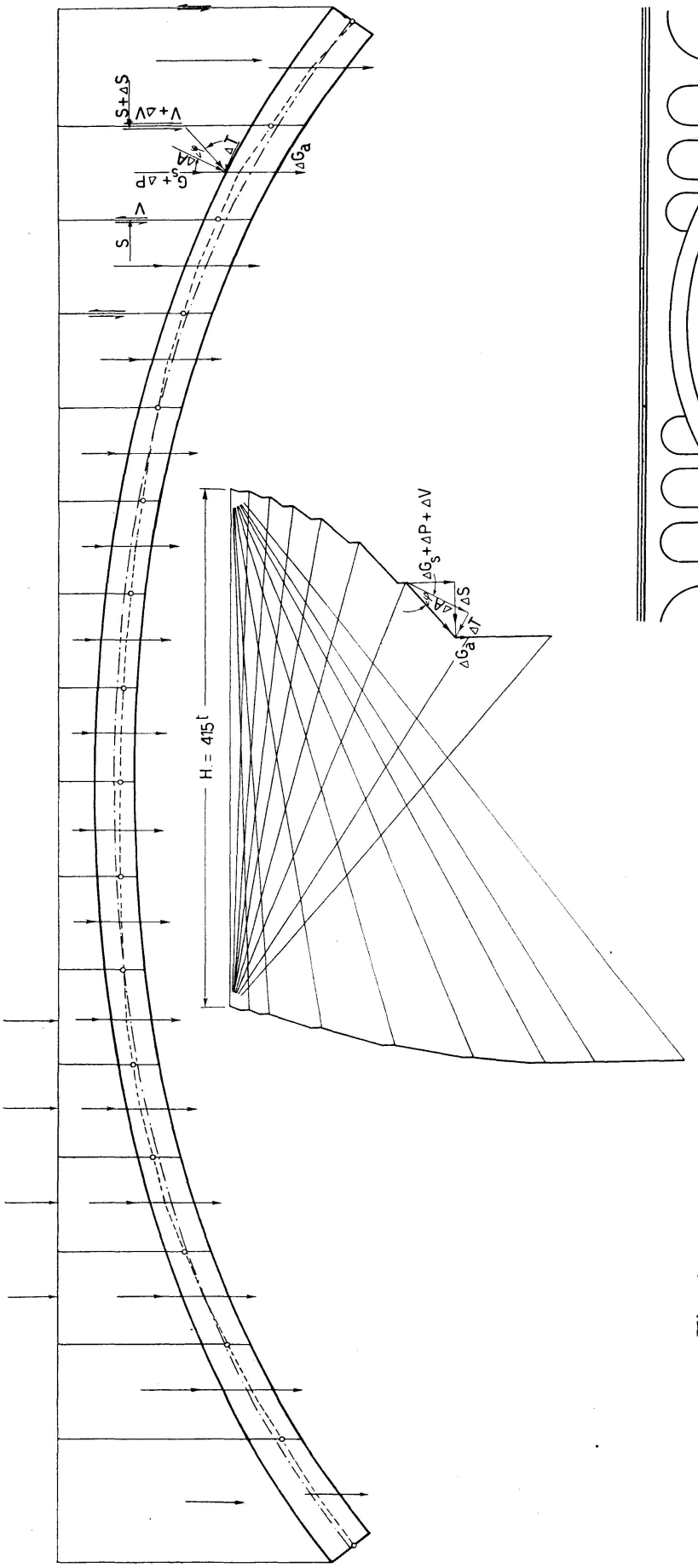

Fig. 6

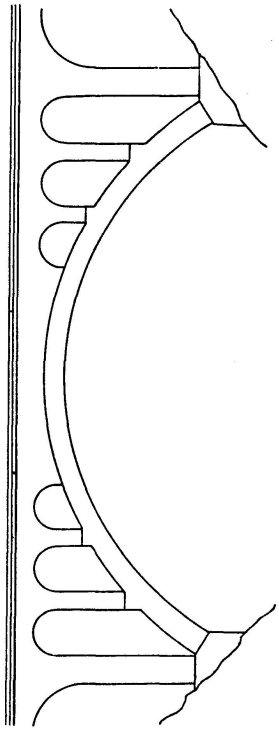

Fig. 7

deformation of the masonry, due to the open joints will produce new cracks in arch and superstructure, and in time the whole construction may be destroyed.

For a more ordinary load, for instance regular highway or railway loadings, it is in consequence important to ensure that the S and V forces can be handled without any relatively great deformations in the superstructure.

For calculations based on the ultimate load bearing capacity it will be necessary to increase the load with a factor of safety n, for instance $n = 2$ or 3. The stresses in the arch must be below the plasticity or yield stresses. For stresses in the superstructure we have the same limit. However, if the superstructure consists of masonry with open joints the frictional forces in the joints will give a stress limit for repeated loads.

For any reconstruction of a voussoir arch it may be of interest to notice that the arch curvature within certain limits is of minor importance for the bearing capacity.

References

A. Selberg: Hvilken belastning tåler våre hvelvebruer. Meddelelser fra Vegdirektören nr. 12, 1946.

A. J. S. Pippard, E. Tranter and L. Chitty: The mechanics of the voussoir arch. Journ. Inst. Civil Engineers. Dec. 1936.

Summary

The investigation shows the dominant influence of the superstructure on the bearing capacity of masonry arches.

The improvement of the superstructure — for instance by injection of cement — will very often be the cheapest and most convenient method for strengthening old arch bridges.

Résumé

Des investigations ont montré que la capacité de charge des arcs maçonnés dépend dans une large mesure de leur superstructure.

Il arrive ainsi très fréquemment que l'amélioration de la superstructure, que l'on peut réaliser par exemple par injection de ciment, constitue le moyen le meilleur et le plus économique pour assurer le renforcement des anciens ponts en arc.

Zusammenfassung

Untersuchungen haben gezeigt, daß die Tragfähigkeit gemauerter Bogen weitgehend von deren Überbau abhängt.

So wird sehr oft eine Verbesserung des Überbaues, wie sie z. B. durch Zementinjektionen erreicht werden kann, das billigste und am besten geeignete Mittel zur Verstärkung alter Bogenbrücken sein.