The compound action of concrete slabs and rolled steel girders for bridge decking: test results

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The Compound Action of Concrete Slabs and Rolled Steel Girders for Bridge Decking, Test Results.

Ueber die Verbundwirkung von Betonplatten und Stahlträgern bei Brückenfahrbahnen, Meßergebnisse.

De la collaboration des dalles en béton et des poutres en acier dans les tabliers de ponts, résultats des mesures.

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Results of Measurements.

With a view to elucidating the distribution of the stresses in a bridge superstructure with concrete slabs, stress measurements in terms of load have been carried out in recent years on a few road bridges in Sweden, where this type of structure is becoming more and more frequent. The load consisted of stationary motor trucks of known wheel pressure and dimensions. The stresses in the steel girders were measured at a certain number of points by means of tensometers or deformation gauges supplied by Messrs. *Huggenberger* of Zürich. The measured lengths adopted were 100 mm for the tensometer and 250 mm for the deformation gauge. In each case the stresses were measured at two points, viz on the upper flange and the lower flange of the girder.

As regards the stress measurements which were made, the following points should be noted when assessing the results.

As already stated, motor trucks (lorries) were generally used for the test loadings, and this enabled the time taken for the tests, during which the bridge had to be closed to traffic, to be curtailed as far as possible.

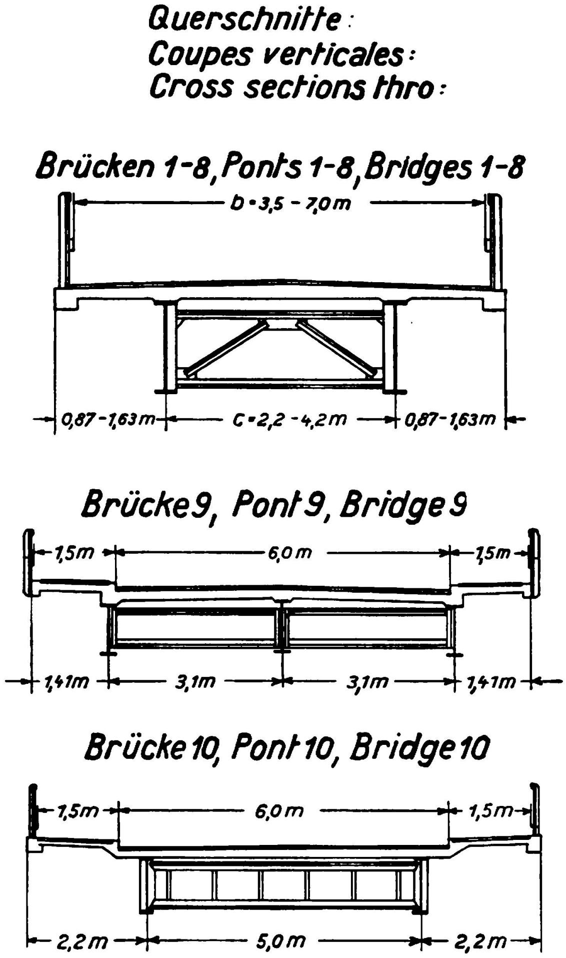
With the trucks available on the spot as loads it was usually impossible to make a loading test equivalent in extent to the calculated traffic load of the bridge. Consequently, the stresses set up during the test loading are comparatively small, so that any sources of error present may cause considerable percentage deviations.

The days on which the tests were to be made had been fixed a long time in advance, and as the motor trucks had been ordered beforehand, it was impossible to alter the times, which meant that the load tests had often to be made in weather which adversely affected both the measurements and their results.

Repeated calibrations were made in order to obtain as far as possible reliable results with the instruments available and under the conditions obtaining at site.

The results, given below, of the measurements on the upper and lower flanges represent the mean of the figures arrived at in this way.

The age of the concrete slabs at the time of carrying out the loading test varied considerably in the several bridges. In a few cases, the loading test was carried out a comparatively short time after the concrete slabs were finished, while in other cases, and due to different circumstances, it was not possible to apply the test until several months after the concrete had hardened. The elastic properties of the concrete at the time the load tests were made therefore varied considerably from one case to another.



Under these circumstances and having due regard to the other difficulties always met with when measurements are made on the actual site, the results obtained cannot be expected to be as accurate as tests carried out in test laboratories. As against this, measurements made at the actual site have the advantage that they can be carried out on full-scale structures and under conditions such as actually obtain. This is rarely the case in test laboratories. The results obtained may therefore be of interest for judging the problem, even though they are subject to certain errors.

Of the bridges on which stress measurements were made, some were statically determinate, while others were continuous girder bridges (Fig. 1). The cross-sections of the bridges are shown in Fig. 1. The main girders consist either of rolled broad-flange girders, or welded plate girders. In some of the bridges, anchor bars are inserted between the slab and the girder, while the others had no anchor bolts. The points of measurement were located either at mid-span or over the intermediate supports.

Table 1 also contains (a) the stresses actually read, and (b) the corresponding stresses calculated on the two following assumptions. In the first case, it is assumed that there is no coöperation between concrete slab and steel girders, while perfect coöperation is assumed in the second case. In the latter case, the full width of the slab is presumed to act; and the ratio n between the modulus of elasticity for steel and for concrete is taken as 10, in accordance with the Concrete Specifications applicable in Sweden.

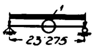
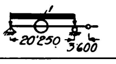
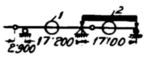
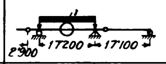
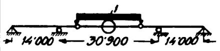
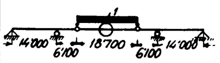
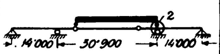
Referring to Table 1, it will be noted that the measured stresses for bridges 1—7 are generally lower than the stress calculation on the assumption of perfect coöperation, which means that the effect of the slab appears to be greater than the calculated figure. This may be due to the fact that the actual value of n does not agree with the value adopted in the calculations, and that the bridge railing may have affected the distribution of the stresses, especially in narrow bridges. The influence of the railing was not allowed for in the calculations.

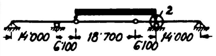
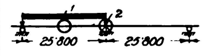
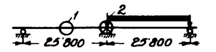
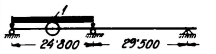
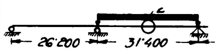
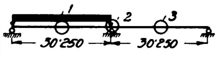
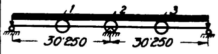
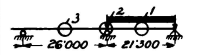
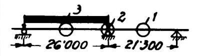
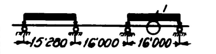
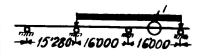
At one of the points of measurement in Bridge 3, a result differing from the above was obtained. The stresses recorded in the top or bottom flange are higher in this case than the values calculated under the assumption of full coöperation. The stresses in the bottom flange deviate by less than 10 %, whereas the measured stress in the top flange falls approximately in the middle between the stresses calculated on the assumption of full coöperation or no coöperation. The result is probably due to the fact that the cohesive forces between slab and girders were partially overcome and that, consequently, there was not complete coöperation.

The results obtained for Bridges 8 and 10, which are comparatively wide ones, indicate that the concrete slab did not coöperate in transmitting the moments to the extent assumed in the calculations. As regards Bridge 8, it should be noted that the test load was applied comparatively soon after the slab had been concreted, in addition to which the temperature was low during the time that elapsed between the concreting and the loading test. Under such conditions, the elastic properties of the concrete may not agree with the assumptions made. As regards Bridge 10, the concrete slab, including its brackets, possibly did not coöperate to its full width as had been assumed in the calculations. This fact is also partly responsible for the measured stresses in Bridge 8 being higher than the calculated figures. These factors must be allowed for when calculating structures of this kind on the assumption of complete coöperation.

In the case of Bridge 9, the measured stresses show a tendency, as regards the negative moments, to exceed the figures calculated on the assumption of full coöperation between concrete slabs and girders. In view of the fact that the stresses are very low and that the sources of error may consequently have a high percentage effect, prudence enjoins that no definite conclusion should be drawn from them. The measured values of the stresses set up by positive moments are lower than those calculated when assuming full coöperation.

Tabelle I Tableau I Table I

Brücke Pont Bridge Nº	b m Siehe Voir See Fig. 1	c m Siehe Voir See Fig. 1	Alter der Betonplatte / Age de la dalle de béton / Age of concrete slab — Monate Mois months	Belastungsfall / Cas de charge / Type of loading	Spannung in kg/cm² Tension en kg/cm² Tension in kg/cm² — berechnet unter Voraussetzung, dass / calculée en admettant: / calculated under the assumption, that — keine Zusammenwirkung zwischen Platte und Balken vorhanden ist. / aucune collaboration entre la dalle et les poutres / no compund action exists between slab and beam — im Messpunkt au point in point						volle Zusammenwirkung zwischen Platte und Balken vorhanden ist, sowie dass n = 10 ist / une collaboration complète entre la dalle et les poutres ainsi qu'un n = 10 / both slab and beam are acting together, and for n = 10						aufgemessen im Messpunkt / relevée au point de mesurage / measurement taken in point						Bemerkungen / Remarques / Remarks
					1		2		3		1		2		3		1		2		3		
					O.k.	U.k.	O.k.	U.k.	O.k.	U.k.	O.k.	U.k.	O.k.	U.k.	O.k.	U.k.	O.k.	U.K	O.k.	U.k.	O.k	U.K	
1	3.5	2.2	2		−289	+289	—	—	—	—	−47	+230	—	—	—	—	± 0	+209	—	—	—	—	Verankerungseisen zwischen Platte und Balken
2	5.0	3.3	4.5		−540	+540	—	—	—	—	−77	+421	—	—	—	—	−21	+313	—	—	—	—	Fers d'ancrage entre la dalle et les poutres
3	6.0	3.6	2.5		+139	−139	−332	+332	—	—	+11	−107	−25	+255	—	—	+55	−98	−3	+217	—	—	Tie-bars for slab and beam
					−434	+434	—	—	—	—	−33	+333	—	—	—	—	−229	+357	—	—	—	—	
4	6.0	3.5	6.5		−549	+549	—	—	—	—	−60	+410	—	—	—	—	−14	+367	—	—	—	—	Desgl. idem id.
					−225	+225	—	—	—	—	−25	+172	—	—	—	—	−6	+178	—	—	—	—	
					—	—	+484	−484	—	—	—	—	+117	−388	—	—	—	—	+92	−382	—	—	

					—	—	+200	−200	—	—	—	—	+49	−162	—	—	—	—	+39	−160	—	—	
5	4.5	2.8	2		−507	+507	+217	−217	—	—	−63	+403	+52	−198	—	—	−26	+374	+52	−161	—	—	
					+131	−131	+216	−216	—	—	+16	−105	+52	−198	—	—	+16	−79	+52	−162	—	—	
6	4.5	2.5 •	5.5		−705	+705	—	—	—	—	−84	+570	—	—	—	—	−74	+566	—	—	—	—	Desgl. idem id.
					—	—	−895	+895	—	—	—	—	−79	+697	—	—	—	—	−75	+640	—	—	
7	5.0	3.0	10.5		−945	+945	—	—	—	—	−112	+710	—	—	—	—	−23	+709	—	—	—	—	Desgl. idem id.
					—	—	−996	+996	—	—	—	—	−118	+748	—	—	—	—	−48	+795	—	—	
8	7.0	4.2	1.5		−600	+600	+314	−314	+229	−229	−61	+490	+48	−261	+23	−187	−130	+516	+172	−287	+95	−221	
					−435	+435	+619	−619	−400	+400	−44	+356	+95	−518	−40	+326	−73	+382	+125	−505	−105	+331	
9	Siehe Voir See	Fig. 1	8.5		−219	+219	+55	−55	+29	−29	−15	+141	+7	−40	+2	−19	+5	+135	+2	−47	+2	−35	
					+39	−39	+59	−59	−254	+254	+3	−25	+7	−42	−18	+164	−1	−36	+5	−58	−5	+127	
10	Siehe Voir See	Fig. 1	7.5		−407	+407	—	—	—	—	+19	+270	—	—	—	—	−9	+231	—	—	—	—	
					−317	+317	—	—	—	—	+20	+212	—	—	—	—	−16	+165	—	—	—	—	

○ 1,2,3 Messpunkt — point de mesurage — point of measurement

 Belastete Lange — Longueur chargée — loaded stretch

O.K. Oberkante — aile supérieure — upper extreme

U.K. Unterkante — aile inférieure — lower extreme

The measurements made gave no information as to the value of the cohesive forces between slabs and girders, or as to the effect of the anchor bolts. To clear up these questions, it may be necessary to apply higher loads to the structures than has hitherto been possible. Nor have the tests explained to what extent the cohesive forces are affected by the deformations and vibrations set up by the traffic load.

Positive moments set up compressive stresses and negative moments set up tensile stresses in the concrete slab. When the latter reach a figure exceeding the tensile strength of the concrete, the concrete slab is weakened, and it can no longer coöperate with the steel girders in transmitting the forces. To ensure coöperation between a concrete slab and steel girders, it is therefore necessary that the tensile stresses in the slab be kept within permissible limits and that the slab has the reinforcing necessary to enable it to do so.

Experience has shown that there is a danger of cracks forming in the concrete slab of these particular structures at points which are exposed to negative moments. In a few cases, cracks developed above the supports in concrete slabs, in bridges of the continuous girder type. According to the specifications applying in Sweden, the reinforcement has been calculated without allowing for the coöperation between, or joint effect of, concrete slab and steel girders. Due to the fact that coöperation took place between slab and girders, higher tensile stresses were set up in the concrete slab than the calculated values, with the result that the reinforcement in the slab was unable to prevent the slab cracking. Check calculations have shown that very often a much bigger amount of ironwork is necessary than is now adopted for concrete slabs above supports if the reinforcing is to take up the tensile stresses which occur in the coöperation between slab and girders.

Summary.

The results of the stress measurements carried out show that coöperation took place in the bridges examined. It is not, however, clear from the measurements whether such coöperation may be assumed with certainty, and to what extent it takes place. Further investigation is necessary on this point.

In bridges of the continuous girder type, the iron reinforcement above the supports must be calculated with regard to the joint effect of concrete slab and steel girders.