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Strength in Structures, Particularly Concrete Walls

La résistance des constructions, et notamment des murs en béton

Die Festigkeit von Bauwerken, insbesondere von Betonwänden

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Common Aspects

Structural materials, that is here metals and concrete, are to some extent heterogeneous in their properties. There can by many reasons for this. It is of importance to know how the material properties vary within a structure in order to decide the kind of control which is most suitable, as well as for choosing the safety factors. During recent years interesting research work has been done regarding these matters.

When a steel beam is rolled from an ingot for example, segregations create certain effects in the beam, so that the flanges have somewhat less strength than the web. Moreover, rolled steel plates acquire a strength perpendicular to the surface which in some cases is much less than that parallel to the surface. The latter circumstance is of course of importance in the design of welded structures.

In steel sections there are also residual *stresses* introduced, due both to thermal processes and to the straightening of the members. In rolled steel beams residual stresses can have values of up to $^1/_3$ or $^1/_2$ of the yield stress. In welded sections, residual stresses appear with values up to the yield stress. Particularly at the Lehigh University, investigations have shown that such residual stresses can have a very unfavorable influence on the buckling load of compressed members [1], [2].

In the following paper some data will be given regarding the strength of concrete in structures compared with the strength of separately-cast test specimens.

Concrete Structures

The compressive strength of concrete is usually considered to be the most important test value characterizing the quality of a concrete. However it is a well-known fact that an ordinary compression tests is not in itself satisfactory. Moreover, a standard test is often not representative for the strength of concrete from the same casting constituting part of a structure.

A cube or a cylinder compressed in one direction between rigid steel platens is not subjected to uniform uniaxial stresses. On the surfaces in contact with the platens friction forces appear preventing horizontal dilatation, and these differ on test specimens of different forms and sizes. The curing, condition of moisture, preparation of compressed surfaces, speed of strain increase and the stiffness of the steel platens are further factors of influence.

All these uncertainties in testing the compressive strength present difficulties in international research cooperation. In order to standardize testing methods in this respect, RILEM recently, 1965, has worked out specified recommendations: "A RILEM method of sampling, making, curing and strength testing of concrete."

The author has made an evaluation of the published data regarding testing to failure of *over-reinforced* concrete beams and *eccentrically* loaded short columns [3]. The test results have been compared with calculated values, using an ultimate strength design theory, recommended by the European Concrete Committee (CEB). In all these cases the assumed strength value is of primary importance. It has been shown that the ratio between calculated and experimental values has a dispersion, which is not wide within each test series belonging to the one author. However, the mean values of the ratios differ significantly from one series to another. This difference probably depends upon the fact that the compressive strengths of the beams or columns cannot safely be correlated to the compressive strengths of separate test specimens of different kinds from one series to another.

Another difficulty in defining the compressive strength under practical conditions has been the circumstance that the strength varies from test to test, even for the same or to all intents the same concrete. For this purpose the CEB has introduced the notion characteristic strength, corresponding to that strenght, below which 5% of the test values in a long series fall. In Sweden, the new specification from 1965 is built up principally in that way, as follows.

Concrete for one series of three test specimens shall be taken from three different batches. The specimens shall be either 15 cm cubes or circular cylinders with diameter 15 cm and height 30 cm. Certain transformation ratios between the respective test values are given.

The requirements are then fixed according to the number of such series, in order that the estimate shall be fair, independent of the number. Generally at the maximum, 10% (in some cases down to 0%) of the number of series may give strengths below the required value, designated for example "K 250". The strength of single test specimens may never fall below 0.8 K.

As mentioned above, the strength of test specimens is often not representative for the strength of the concrete from the same casting in a structure. This is particularly obvious concerning vertically-cast columns and walls. The author also evaluated some published data from *centrally* loaded short columns. The calculated limit stresses with due regard to unintentional eccentricities are in these cases lower compared with those at pure bending and the values are also more widely dispersed than these. Test values from E. HOGNESTAD [4] gave, for example, at a cylinder strength of 370 kp/cm² a limit stress in the corresponding column ("A – 1 a") which was only 76% of this value.

N. PETERSONS at the Cement and Concrete Research Institute, Stockholm, has made a systematic study of the unintentional strength variations in concrete columns [5]. The columns were reinforced and cast vertically with different intentional concrete strengths. After curing in water and hardening cylinders with diameter 15 cm were drilled out vertically from different levels in the columns. The cylinders were then tested in compression. The strengths varied systematically, with the lowest strength values in the top regions. Further these values were lower than the strengths of the corresponding separately-cast test cylinders, cured in the same manner as the columns. PETERSONS stated, that this reduction was located in a region situated about 60 cm from the top of the column, whereas in the lower parts, the strength of the cylinders from the column had the same or higher strength than the separately-cast test specimens. PETERSONS found the relative reduction of strength in the top region increased with increasing strength level.

It was known from earlier investigations, e.g. by A. JOHNSON [6] and L.-E. LARSSON [7], that similar strength reductions in the top regions also appeared in concrete *walls*. It was therefore highly desirable that a more extensive systematic study be made of this subject. For this reason, a research project has been taken up at the author's Institution for structural engineering and bridge building, Stockholm, in cooperation with N. PETERSONS and carried out by J. BHARGAVA. The research is not yet finished, but some results can be given here. A complete report will be published later.

The test walls have a surface area of $1.5 \times 1.5\ \mathrm{m}^2$, and they are cast vertically in steel forms. The main series had a thickness of 16 cm, but other series, not reported in this paper, were made with thickness of 12 and 20 cm, some non-reinforced and some reinforced. Together with each wall special test specimens were cast, six 15 cm cubes and six circular cylinders, 15 cm in diameter and 30 cm in height. Three cubes and three cylinders of those were cured according to the then valid Swedish Concrete Specifications 1949, denoted below as "Sw. Stand.", that is, combined curing under water and storing in laboratory air. The other six specimens were cured in a similar way as the corresponding walls, below denoted "site tests". From each wall six 15 cm cubes were sawn out after hardening and six cylinders, 15 cm in diameter and 30 cm in height, were drilled out vertically. They were taken in equal numbers from three different levels of the walls, namely bottom, middle and top level.

Five different kinds of curing methods were used, which are listed below.

Curing method 1: Stripping of steel forms after 24 hours, top surface covered immediately after casting and up to 24 hours with wet sacks, then under water for 27 days.

Curing method 2: Same stripping, curing 28 days in laboratory air, humidity 50—70%.

Curing method 3: Same stripping, curing 4 days in water and 23 days in laboratory air, i. e. approximately the same curing as given in Swedish Standard.

Curing method 4: Same stripping, all surfaces covered with wet sacks for 13 days, then in laboratory air 15 days.

Curing method 5: Rapid Hardening Portland cement, stripping after 6 hours, curing under wet sacks 5 days, then in laboratory air 9 days. Age at testing, 14 days.

One full series was made with an intentional cube strength of about 250 kp/cm^2, denoted "K 250", and another full series was made with an intentional cube strength of about 600 kp/cm^2, denoted "K 600".

The table gives the *results* from these two series.

The following *conclusions* can be drawn from the results in the table.

In all the walls the strength at the top level was less than at the bottom.

For walls of concrete *K 250*, the *cubes* from the top level gave between 18 and 59 kp/cm^2 less strength than those from the bottom level, including walls with Rapid Hardening Portland cement. This reduction corresponds to between 5 and 17%. The tests with *cylinders* gave only a slight difference between the top and bottom levels.

For walls of concrete *K 600*, the *cubes* from the top level gave between 94 and 169 kp/cm^2 less strength than those from the bottom level, including walls with Rapid Hardening Portland cement. This reduction corresponds to between 15 and 29%, that is much more than for concrete K 250. In this case the *cylinders* gave a difference between the top and bottom levels of the same relative order, or 21—33%.

A comparison between top level *cube* strength from walls with concrete *K 250* and strength of cubes cured as the walls, "site cube strength", shows in cases 1, 3, 4 and 5 rather similar values, the ratios varying between 0.93 and 1.02. In case 2, corresponding to dry curing, the top level cube strength was greater than the "site cube strength", the ratio being 1.20.

Table

		Curing method Nr.									
		1		2		3		4		5	
		Portland cement concrete, age 28 days, strength kp/cm²								Rap. Hard. Portl. cem. 14 days	
		Cubes	Cyl.	Cubes	Cyl.	Cubes	Cyl.	Cubes	Cyl.	Cubes	Cyl.
Concrete K 250	Cubes and cylinders from walls: top level	327	252	263	208	302	244	281	226	326	261
	Cubes and cylinders from walls: middle level	325	257	309	232	323	252	291	242	336	268
	Cubes and cylinders from walls: bottom level	345	260	320	221	348	244	340	248	366	282
	Site test specimens	333	273	219	184	307 (site test specimens and Swedish Standard tests together)	252 (site test specimens and Swedish Standard tests together)	301	239	319	278
	Swedish Standard tests	314	258	304	257			280	256	320	276
Concrete K 600	Cubes and cylinders from walls: top level	527	378	462	352	427	359	420	311	569	462
	Cubes and cylinders from walls: middle level	568	447	570	416	500	401	525	408	645	490
	Cubes and cylinders from walls: bottom level	621	479	610	474	575	450	589	465	679	507
	Site test specimens	588	436	478	364	546 (site test specimens and Swedish Standard tests together)	414 (site test specimens and Swedish Standard tests together)	508	387	729	495
	Swedish Standard tests	592	490	589	457			522	435	721	637
K 250	Bottom level minus top level strength	18	8	57	13	46	0	59	22	40	21
	Top level test / Site test	0,98	0,92	1,20	1,13	0,98 (site test and Swed. Stand. together)	0,97 (site test and Swed. Stand. together)	0,93	0,95	1,02	0,94
	Top level test / Swed. Stand.	1,04	0,98	0,87	0,81			1,00	0,88	1,02	0,95
K 600	Bottom level minus top level strength	94	101	148	122	148	91	169	154	110	45
	Top level test / Site test	0,90	0,87	0,97	0,97	0,78 (site test and Swed. Stand. together)	0,87 (site test and Swed. Stand. together)	0,83	0,80	0,78	0,93
	Top level test / Swed. Stand.	0,89	0,77	0,78	0,77			0,80	0,72	0,79	0,73

The *cylinders* from the top level showed strengths which were all *less*, or in one case equal to, the "site cylinder strength". That means that the site cylinder strength gives values which are on the *unsafe* side.

A similar comparison with the Swedish Standard test specimens gives on the whole the same picture, except in case 2, where both cube and cylinder tests according to Swedish Standard have given values on the unsafe side, apparently because curing method 2 for the wall has been too dry.

For the walls with concrete *K 600*, the following results were found. All cubes and cylinders taken from the top level showed *less* strength than the corresponding site tests and Swedish Standard tests, with ratios at the minimum, for cubes 0.78 and for cylinders 0.72. That is a striking result, showing that the strength in the top of a wall might be only 72% of the standard test strength. However, this is in agreement with some results found in the case of columns.

At present it is too early to draw any conclusions regarding the influence of curing methods. It is obvious that the circumstances referred to above must be taken into consideration when choosing safety factors.

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Summary

Both steel and concrete structures show heterogeneous material properties, some of which are of systematic character. This is important to know in order to deciede the kind of control which is most suitable, as well as for choosing the safety factors. In the paper new data are given regarding the strength of concrete in vertically cast walls, showing systematic variations.

Résumé

Qu'elles soient métalliques ou en béton, les constructions sont composées de matériaux dont les propriétés sont hétérogènes, ces variations ayant pour certaines de ces propriétés un caractère systématique. C'est là un point important à connaître pour décider du type de contrôle le mieux approprié et choisir les coefficients de sécurité. L'auteur présente de nouvelles données concernant la résistance du béton dans les murs construits selon un coulage vertical et il montre l'existence de variations systématiques.

Zusammenfassung

Sowohl bei Stahl- als auch bei Betonkonstruktionen sind die Materialeigenschaften heterogen verteilt; für gewisse dieser Eigenschaften weist die Verteilung einen systematischen Charakter auf. Es ist wichtig, dies zu wissen, um die am besten geeignete Prüfungsart zu bestimmen und die Sicherheitsfaktoren festzulegen. Der Autor bringt neue Angaben über die Betonfestigkeit bei vertikal gegossenen Wänden vor und zeigt, daß es systematische Veränderlichkeiten gibt.

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