**Comparison of in-situ strengths and quality tests of concrete**

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# COMPARISON OF IN-SITU STRENGTHS AND QUALITY TESTS (OF CONCRETE)

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D.A. SINCLAIR

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# PREFACE

In studies of the safety of reinforced concrete structures three aspects of concrete strength are relevant: the strength of concrete specified, the strength and variability of concrete supplied, and the strength and variability of the concrete in the actual hardened structure. Information on the last item is meagre, but is needed particularly for research studies. This paper is a valuable contribution toward filling this need.

The Division here records its thanks to D. A. Sinclair for translating this paper, and to W. G. Plewes of this Division, who checked the translation for technical accuracy.

Ottawa
April 1976

C.B. Crawford
Director
Division of Building Research

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(Vergleich von Bauwerkfestigkeiten und Güteprüfungen)

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# COMPARISON OF IN-SITU STRENGTHS AND QUALITY TESTS

# (OF CONCRETE)

## 1. Introduction

DIN 1045[1] and DIN 1048[3] constitute the basis for appraising concrete quality. Accordingly, the strength of 28-day-old test cubes of the same material as the finished concrete work serves as a yardstick. Many building contractors argue that when the cubes attain the required concrete strength the desired performance is assured, provided no visible defects appear in the construction. Of considerably greater interest to the engineer than the strength of the test cube at the designing and estimating stage, might be to know what in-situ strengths are normally available or can be expected from concrete, steel concrete and pre-stressed concrete structures, respectively. However, little is known about this matter and, moreover, views differ as to how strength values ascertained in situ are to be appraised[4,5].

The question of whether the compressive strength of a specimen produced and stored in compliance with the standards represents the strength of a structural part constructed from the same concrete, and if so to what extent, is almost as old as concrete and steel-reinforced concrete construction itself[6]. Many laboratory tests of the compressive strength and strain behaviour of concrete have indeed been carried out, as well as tests on reinforced and unreinforced components produced from them, and on the basis of the knowledge thus obtained methods of calculation and design specifications have been developed. Nevertheless, our knowledge of the actual conditions present in finished construction work is still very limited. All we can say is that under ordinary conditions, i.e., if a structure has been erected in conformity with obligatory technical requirements, the margins of safety inherent in the design specifications will provide sufficient protection against present inaccuracies.

Hitherto only one contribution has appeared in which cube strengths are compared with in-situ strengths. Moreover, this can scarcely be regarded as representative of concrete construction in general, since it deals with a large-scale mass concrete project installed as a prototype[7,8]. Otherwise, all we have are results on buildings where damage is suspected[9], and the results of laboratory tests in which attempts have been made to simulate in-situ conditions[10,11,12].

Thus, final conclusions on the subject of structural strength appear premature, and "... complete clarification of this problem will have to await the conclusion of many, possibly less impressive, but undoubtedly essential investigations"[13].

## 2. Test Procedure and Results

By studying typical steel-reinforced and pre-stressed concrete it was hoped to gain a more precise definition of the conditions prevailing on normal construction sites. The tests were carried out by the author as part of a more extensive study[14] in the course of his activity at the Institute for Building Material Science and Steel Concrete Construction of the Technische Universität Braunschweig. The chosen method of in-situ investigation was in all cases the taking of drill core samples in the manner shown in Figure 1. The advantage of this "destructive" method, compared with all nondestructive ones, e.g., Reference 15, is that it provides direct information on the internal structure of the material and immediately reveals processing defects (see Figure 2). The compressive strength is determined directly from concrete specimens taken from in-situ structures. There is no need for the intervention of a more or less accurate calibration curve of the kind required in nondestructive testing. The accuracy of the strength values obtained from specimens taken "destructively" is limited only by errors of the same order of magnitude as those which regularly occur in tests of concrete compressive strength.

### 2.1 Results of routine investigations

It is the task of all building material testing institutions to undertake routine quality tests on concrete cube specimens on behalf of applicants from every sector of the construction industry. In addition, in-situ investigations of structures are carried out when complaints are received about components or when no quality records have been provided for the installed concrete. Inspection of the voluminous data which have accumulated from such routine testing over four years in the Institute for Building Material Science and Steel Concrete

Construction of the Technische Universität Braunschweig allows several conclusions to be drawn about quality conditions in concrete construction.

From the results of the quality tests according to DIN 1048 we can take several features which are characteristic of certain grades of concrete and types of structure. The analysis of about 9,600 complete test certificates from the years 1964 to 1967 revealed the following:

1. Regardless of the grade of concrete, the year of construction and the type of structure, the distribution of the values corresponds, in good approximation, to a standard distribution which can be clearly described with sufficient accuracy by a mean value for random samples $\bar{\beta}_{w28}$ (= $\bar{x}$) and a standard deviation s.

$$y = \frac{n}{s \cdot \sqrt{2\pi}} \cdot e^{\left[-\frac{1}{2} \cdot \left(\frac{\bar{x} - x}{s}\right)^2\right]} \qquad (1)$$

2. The mean values and scatter do not differ from year to year; thus, there is no evidence of an effect of the state of the construction market on the care of execution.

3. The anticipated value for B 225 is somewhere in the vicinity of 350 kp/cm$^2$, for B 300, 400 kp/cm$^2$ and for B 450, 500 kp/cm$^2$. In other words, the ratio of cube strength to theoretical strength decreases with increasing concrete grade. This is evidently independent of the type of construction (Figure 3).

4. The scatter decreases somewhat with increasing concrete grade.

5. The cubes can be expected to fall short of the theoretical strength values in about 10 to 15% of all cases.

During the same observation period a total of about 1,350 core samples were taken from 200 outwardly acceptable structures of known theoretical concrete grade for verification of the in-situ concrete compressive strength. The core tests were in general motivated by negative criteria, e.g., the absence of test cubes. All the specimens taken were more than two months old. These building sites, which were not satisfactory in every respect, revealed the following (Figure 4):

1. Even though the theoretical strength values were attained in a number of

cases, nevertheless the structural strengths, on the average, were only 70 to 80% of the theoretical concrete grade, although the specimen ages were over four weeks.

2. In many cases the mean in-situ strength reached only 50% or less of the theoretical strength.

3. Both for individual structures and for groups representing different types of structures the standard deviations were considerably greater than those obtained from the test cubes, and greatly exceeded anything that could be called an "acceptable" scatter. The large standard deviations of roads might have been due to weathering.

4. Although, in general, less than 50% of the specimens attained the theoretical values, the conditions found in bridges, roadways and single-family houses were somewhat better. In the case of bridges this could be attributed to smaller scatters, and in the case of roads and houses to larger excess strength values.

## 2.2 Comparative in-situ tests

To help clarify the question of the extent to which traditional cube tests are a measure of in-situ strength and the relationship of the latter to the theoretical strength we investigated a total of 24 building sites and prefabrication plants. The structures and structural parts involved met normal standards and were not subject to complaints. The projects included bridges as well as high-rise buildings and tall engineering structures. The building enterprises ranged from small brickyards to large construction firms dealing predominantly in pre-stressed concrete construction. The manufacture and storage of cube specimens was carried out in the manner normally applied by each enterprise. Core samples were taken at ages of two to three weeks by members of the Institute. All specimens were tested in the Institute at an age of 28 days.

Comparison of the standard deviations obtained at the building sites with the criteria laid down by Rüsch(17) or Conrad(18) for cube tests shows (Figure 5) that in general the selection of building sites or construction firms was not untypical. The test cube scatters obtained fit the general standard; similarly, the cube results from these structures conform to the values from the routine investigations mentioned above. As expected, the in-situ strength values are somewhat less favourable: whereas only 25% of the cube values fall outside the "acceptable" range, 33% of the drill core values do so.

Figure 6 shows the relationship obtained between the in-situ strength $\beta_{Bau}$ and the cube strength $\beta_W$. Linearity tests in accordance with Reference 16 do not rule out a rectilinear relationship between $\beta_W$ and $\beta_{Bau}$; the correlation with r = 0.93 is very close. The regression calculation gives

$$\beta_{Bau} = 17 + 0,81 \cdot \beta_w \tag{2}$$

as a functional relationship.

This expression can be approximated by

$$\beta_{Bau} \cong 0,85 \cdot \beta_w \tag{3}$$

The graph indicates that the approximation is very good and lies within the confidence interval determined by the regression calculation. The relations between the theoretical concrete B grades on the one hand and the strengths of the cube specimens $\beta_W$ or the core specimens $\beta_{Bau}$ on the other, are shown in Table I. The lowest fractile is from a bridge construction site where the execution left much to be desired and where even the standard deviations of the test cubes according to Reference 17 lead to a poor assessement.

By assembling the data in larger groups according to concrete grades, types of structures and methods of production, a number of common features and more generally valid points of view were developed:

1. Both for cubes and core specimens the ratio of specimen to theoretical strength decreases with increasing concrete grade (Figure 7). The decrease is more rapid for the in-situ strengths. This corresponds to the tendency noted in the routine tests according to 2.1.

2. Within any strength group the differences between structural parts and types of construction produced under different manufacturing and posthardening conditions could be regarded as significant in some cases, but were not very important as a whole.

3. Compressive cube strengths averaged about 37% above the desired compressive strength, whereas the in-situ strength averaged about 15% above (Table I).

As a rule, in structures erected with normal care the in-situ strength reaches the theoretical value. If the execution is less conscientious, as suggested by the absence of quality controls in the cases dealt with in Section 2.1, this relationship appears much less favourable.

4. The 5% fractiles of the in-situ strengths are, in the normal case, about 20% to 30% below the theoretical strength. At less well-run building sites, however, substantially less favourable values may be expected.

5. As far as the in-situ strength values are concerned the bridge structure which was deemed generally excellent showed no advantage whatever over the other types of construction (Figure 8).

## 3. Conclusions

If the results of the investigation are applied to the concrete quality classification of DIN 1045 E (yellow form)[2], we get the conditions presented in Table II. It is clear from this that the test cubes as a whole continue to meet future requirements. The specifications for in-situ strengths (DIN 1045 E, Section 7.3.7) do not appear unreasonable either and seem altogether attainable. However, in order to avoid diagrammatic constructions from this section, it should be reformulated and directed to the determination of a fractile. Something like the following formulation can accordingly be derived from the test results.

In the in-situ concrete strength analysis by the testing of drill cores the compressive strength of a specimen at least 20 days old must not, on the average, fall below the values of Table I, column 3 ($\beta_{Wm}$). For concretes of grades Bn 450 and Bn 550 it must reach 0.9 times this value. Otherwise, a sufficiently large number of samples must be taken so that the 5% fractiles of the in-situ strength can be determined. The 5% fractiles of the drill core strengths must not fall below 0.7 times the values of Table I, column 3, and for concrete of grades Bn 450 and Bn 550 they must correspond to 0.65 times this value.

Taking the age of the concrete into account by conversion factors, as hitherto provided for in Section 7.3.7, seems pointless. Generally, the conditions of setting of the in-situ concrete as well as the curve of setting of the cement employed are not known in sufficient detail, so that the introduction of time factors will constitute only a vague estimate. For most cases it ought to be sufficient to demonstrate from the drill core strength values whether the stability and utility of a building are assured at the time of the inspection.

The numerical strength required for proof of stability is given in DIN 1045 E for all concretes as $\beta_R = 0.7 \cdot \beta_{W28}$. It was found here that the ratio $\alpha_{BS}$ = in-situ strength:theoretical strength, decreases with increasing concrete grade, and this holds for the mean values and for the fractiles. Hence, retaining the same factor of $0.7 \cdot \beta_{W28}$ for all concrete grades appears questionable. Table III shows the conditions. It is suggested that for concretes of higher grade, i.e., Bn 350 and higher, the value $\beta_R = 0.6 \cdot \beta_{W28}$ be chosen so as to retain an adequate margin of safety between the numerical strength $\beta_R$ and the 5% fractile of the in-situ strength and keep it approximately equal for all concretes.

The structures and manufacturers studied in general met ordinary standards. Nevertheless we cannot simply assume that these results are representative of all concrete and steel concrete construction. They may reflect only part of it. It would therefore be desirable to make similar investigations in other places and on other types of structures so that the general validity of the results presented here may be verified at least on a spot-check basis.

In conclusion, we wish to thank the directors and all the co-workers of the Institute for Material Science and Steel Concrete, Technische Universität Braunschweig, who were involved in the execution and evaluation of the investigation for their valuable support.

## Summary

Investigations were carried out on structures and components at more than 20 construction sites and storage yards of precasting factories meeting normal standard requirements with regard to accuracy in production and placement of concrete. It resulted therefrom that in most of the structures investigated the structural strengths after 28 days attained on an average the theoretical concrete quality; fractile values were below by about 20 to 30%. It has been explained that the specification required in DIN 1045 E with regard to structural strengths can, with some accuracy, be maintained without any difficulty, but that it should suitably be completed by stating a fractile. On the basis of the test results it was recommended to modify the specified strength of higher concrete qualities stated in DIN 1045 E as a constant value $\beta_R = 0.7 \cdot \beta_{W28}$.

## References


[1] DIN 1045 — Bauwerke aus Stahlbeton — Ausgabe November 1959
[2] DIN 1045 — Beton- und Stahlbetonbau, Bemessung und Ausführung — Entwurf März 1968
[3] DIN 1048 — Bestimmungen für Betonprüfungen bei Ausführung von Bauwerken aus Beton und Stahlbeton — Kreuzausgabe Februar 1957
[4] Reiter, E. L.: Gewährleistung von Betongüten. Die Bauwirtschaft, 1967, H. 40, S. 928—929
[5] Fuchs, G.: Zur Gewährleistung von Betongüten. Die Bauwirtschaft, 1968, H. 10, S. 244—245; Erwiderung zu [4].
[6] Berndt, O.; Preuss, E.: Versuche zum Vergleich der Würfelfestigkeit des Betons zu der im Bauwerk erzielten Festigkeit. Deutscher Ausschuß für Eisenbeton, Heft 36, Berlin 1915.
[7] Henzel, J.; Grube, H.: Festigkeitsuntersuchungen an Bauwerksbeton und zugehörigen Gütewürfeln. Der Bauingenieur, 41 (1966), H. 12, S. 487—491
[8] Mehmel, A.: Über einige Grundlagen des modernen Massivbaus. Der Bauingenieur, 42 (1967), H 3, S. 77—83
[9] Weinhold, J.; Meyer, H-G.: Streuung der Betondruckfestigkeit im Bauwerk. Beton- und Stahlbetonbau, 1961, H. 8, S. 200—201
[10] Petersons, N.: Strength of Concrete in Finished Structures. Kungl. Tekniska Högskolans Handlingar Nr. 232 (1964), Stockholm
[11] Campbel, R. H.; Tobin, R. E.: Core and Cylinder Strengths of Natural and Lightweight Concrete. ACI Journal, V. 64, No. 4, April 1967, S. 190—195
[12] Bloem, D. L.: Concrete Strength in Structures. ACI Journal, V 65, March 1968, S. 176—187
[13] Lewicki, B.: Die Beziehungen zwischen der Festigkeit des Betons in Konstruktionen, der Berechnungsfestigkeit und der Kontrollfestigkeit an Probekörpern unter Berücksichtigung der Streuung. Hauptreferat aus dem Kolloquium „Beton" in Dresden, 17.—19. 6. 1968, veranstaltet von der TU Dresden und der Deutschen Bauakademie Berlin
[14] Lewandowski, R.: Beurteilung von Bauwerksfestigkeiten an Hand von Gütewürfeln und -bohrproben. Schriftenreihe der Institute für Konstruktiven Ingenieurbau der Technischen Universität Braunschweig: Heft 3 aus dem Institut für Baustoffkunde und Stahlbetonbau, Direktor Prof. Dr.-Ing. K. Kordina. Werner-Verlag, Düsseldorf 1971
[15] DIN 4240 — Kugelschlagprüfung von Beton mit dichtem Gefüge, Richtlinien für die Anwendung — Ausgabe April 1962
[16] Heinhold, J.; Gaede, K-W.: Ingenieur-Statistik. R. Oldenbourg-Verlag, München—Wien 1964
[17] Rüsch, H.: Zur statistischen Qualitätskontrolle des Betons. Materialprüfung, 6 (1964), H. 11, S. 387—394
[18] Conrad, D.: Beitrag zur Beurteilung der Gleichmäßigkeit von Beton. beton, 1966, H. 5, S. 202—205


## Table I

Relation between theoretical concrete grade B and cube and in-situ strengths

| Type of specimen | Mean value $\overline{\alpha}$ | | | 5% fractiles $\alpha_{\varepsilon}$ | | |
|---|---|---|---|---|---|---|
| | min | max | Overall mean | min | max | Overall mean |
| Cube spec. $a_{WS} = \beta_{W} \cdot B$ | 0,95 | 2,08 | 1.37 | 0,73 | 1,18 | 0.94 |
| Drill core $a_{BS} = \beta_{Bau} / B$ | 0,88 | 1,79 | 1,15 | 0,54 | 0,92 | 0,73 |

## Table II

Comparison of DIN 1045 E grades with test results

| DIN 1045 E | | Cubes | | Drill cores | |
|---|---|---|---|---|---|
| $\beta_{Wm}$ | Bn | $\bar{x}$ | $x_{0,05}$ | $\bar{x}$ | $x_{0,05}$ |
| 200 | 150 | ~ 295 | ~ 190 | ~ 260 | ~ 170 |
| 300 | 250 | 415 | 285 | 345 | 215 |
| 400 | 350 | ~ 510 | ~ 380 | ~ 410 | ~ 275 |
| 500 | 450 | ~ 585 | ~ 470 | ~ 460 | ~ 325 |

## Table III

Relation between numerical strength $\beta_R$ and the 5% fractile of the in-situ strength

| Bn | $\beta_{Wm}$ | $0.7\ \beta_{W28}$ | $0.6\ \beta_{W28}$ | $x_{0,05}$ | $x_{0,05} - 0.7\beta_{W28}$ | $x_{0,05} - 0.6\beta_{W28}$ |
|---|---|---|---|---|---|---|
| kp/cm² | kp/cm² | kp/cm² | kp/cm² | kp/cm² | kp/cm² | kp/cm² |
| 150 | 200 | 105 | 90 | ~ 170 | 65 | 80 |
| 250 | 300 | 175 | 150 | 215 | 40 | 65 |
| 350 | 400 | 245 | 210 | ~ 275 | 30 | 65 |
| 450 | 500 | 315 | 270 | ~ 325 | 10 | 55 |

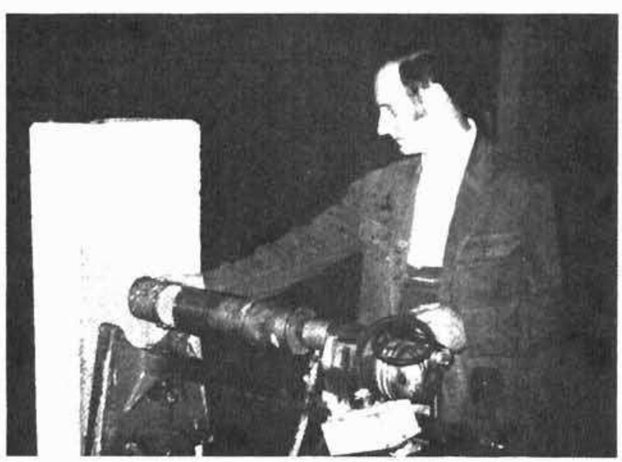

Fig. 1

Sampling of a drill core from a column head with a wet core-drilling machine

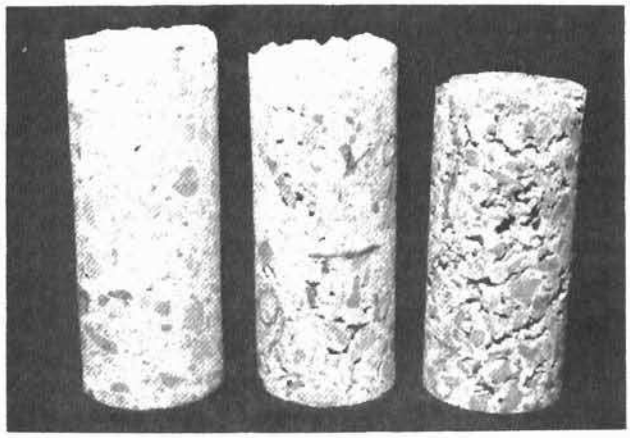

Fig. 2

Concrete drill cores from a motorway bridge.

Left: well compacted concrete of high compressive strength;

centre: concentration of shrinkage cavities suggesting compaction deficiencies;

right: very bad compaction which was invisible on the outside of the structure

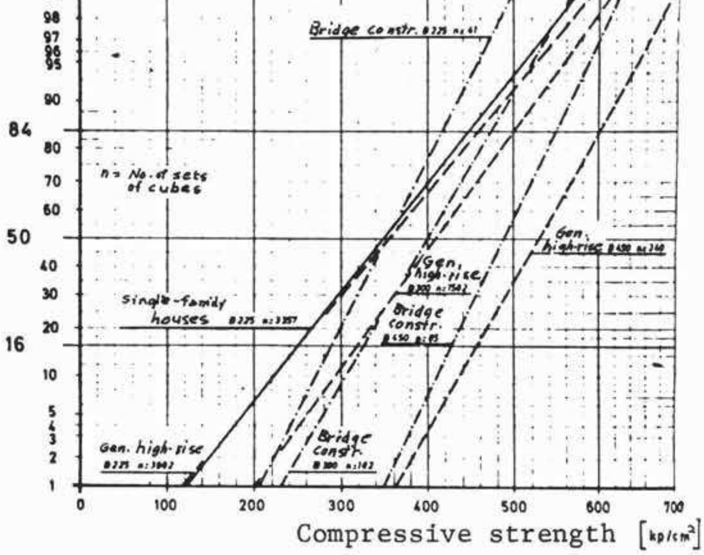


Fig. 3

Results of more than 9600 concrete quality tests on cubes of 20 cm arris length according to DIN 1048; period of record: 1964 through 1967; representation in the probability grid

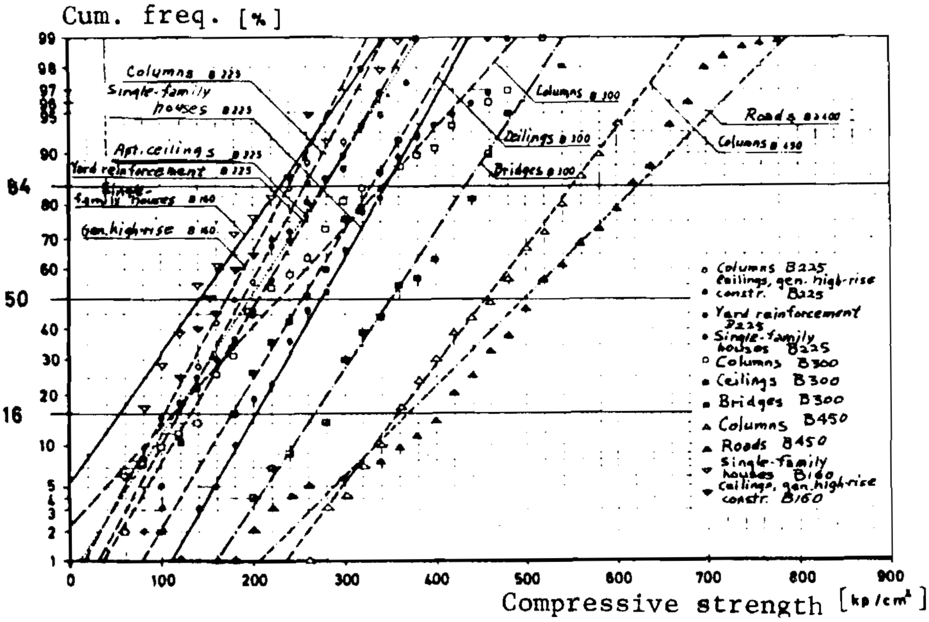


Fig. 4

Findings of subsequent tests carried out on more than 200 structures by means of drill cores; age of test specimens > 2 months; representation in the probability grid

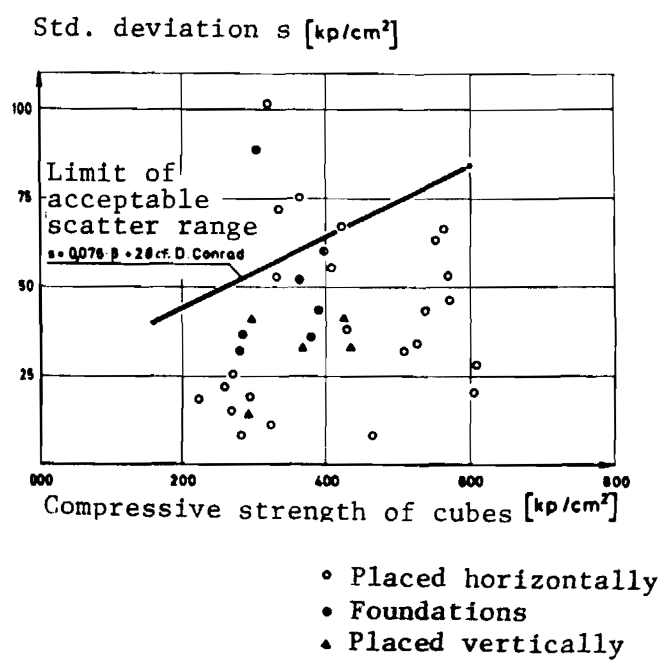


Fig. 5

Comparison of standard deviations s of quality cubes, determined on the structures investigated, with the criteria according to Conrad[18]

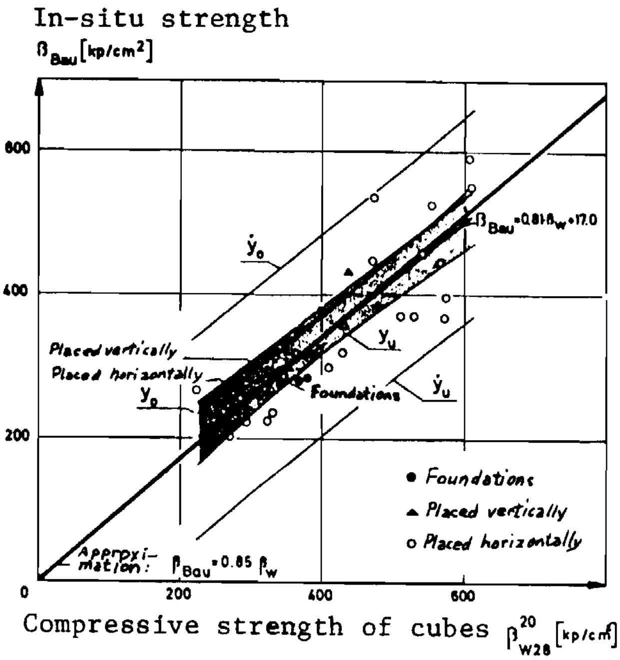


Fig. 6

Relation, determined at 24 construction sites, between structural strength $\beta_{Bau}$ and compressive strength of quality cubes $B_W$

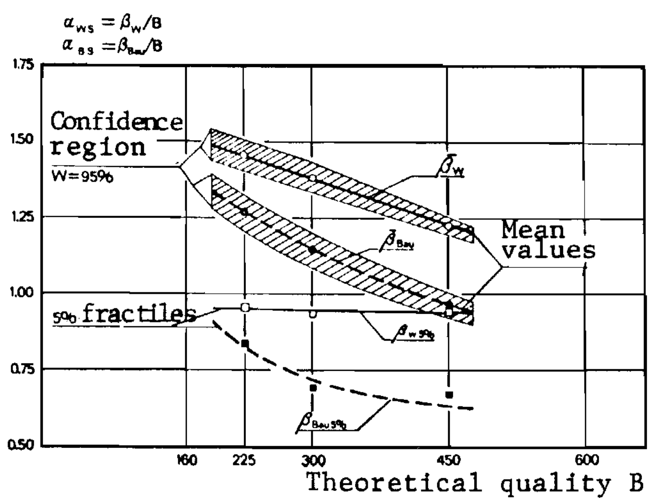


Fig. 7

Relations, determined by way of tests, between theoretical concrete quality B and compressive strength of quality cubes $\beta_W$ and of structural concrete $\beta_{Bau}$

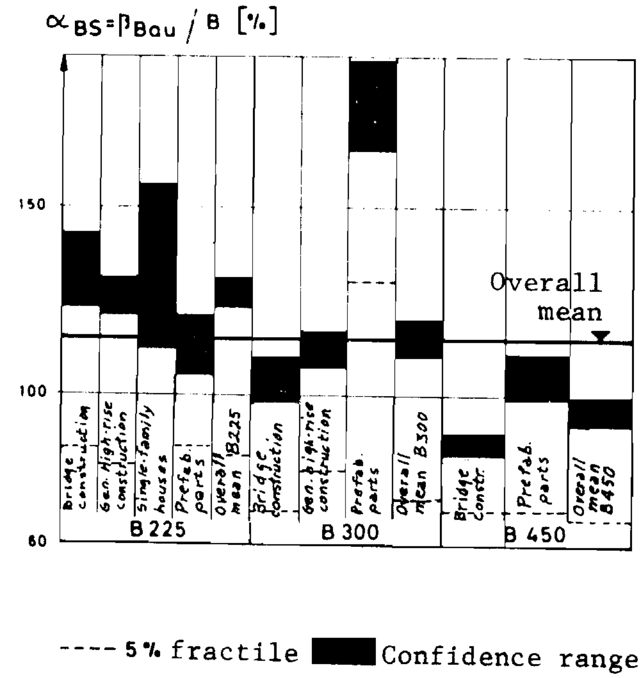


Fig. 8

Comparison of structural strength $\beta_{Bau}$ and theoretical concrete quality B. Classification according to types of structures