# NDT
# Strength of old timber

## TEST CORES FROM 50–400 YEAR OLD TIMBER INDICATES STRENGTH OF OLD TIMBERS CORRESPONDS TO THAT OF NEW


**Wolfgang Rug** **Axel Seemann**

**Non destructive testing has proved to be a useful way of determining the strength of old construction timbers, confirm Wolfgang Rug and Axel Seemann of the Bauakademie, Berlin. The authors in a significant number of tests, did not observe the expected decrease in strength of old timbers**

Wolfgang Rug et Axel Seemann confirment que les test non-déstructifs sont une bonne méthode pour déterminer la résistance des vieux bois de construction. Au cours d'un nombre considérable de tests les auteurs n'ont pas constaté la diminuition de la résistance des vieux bois de construction à laquelle ils s'attendaient.

## Definition of the problem

For a long period, wood was the one and only building material at people's disposal in adequate abundance. Timber structures determined the architecture, engineering and technology of building and construction in many fields for millenniums. In the Middle Ages – with the erection of roof systems, floors, framework structures and bridges – carpenter's timber construction achieved a workmanlike perfection.

There are a great number of serviceable roof, floor and hall structures in industry, in agriculture and in public buildings from the first flowering of timber engineering at the beginning of this century. The maintenance and preservation of these buildings and structures has become increasingly significant. Much experience was gained in the GDR for a period of many years in the fields of the estimation, evaluation and repair of building failures. The decision to be taken on the type and extent of the maintenance and preservation measures and activities being required was preceded by an analysis of the structural state of repair, ref. 1.

At the stage of the evaluation of the structural state of repair, the responsible engineer or architect would provide data concerning the existing loadbearing capacity and structural stability. For this purpose, he or she needs reliable information and data concerning the actual strength of the timber and of the connections.

### Determination of strength

The determination of the data and particulars concerning the strength must, in general, be accomplished by means of built-in timber and is thus subject to a number of restrictions which must be taken into account in the selection of suitable methods for determining the strength.

The evaluation of the loadbearing capacity of the connections is even more difficult and requires special knowledge and experience with regard to the historical development of the constructional principles in timber construction.

The authors focused their studies and investigations on the partial subject of the strength determination; in particular the determination of the compression strength parallel to the grain of new and old timber by means of test cores (hereinafter referred to as $\sigma_{BK}$), and the comparison with the compression strength as determined by means of the standard test specimens (hereinafter

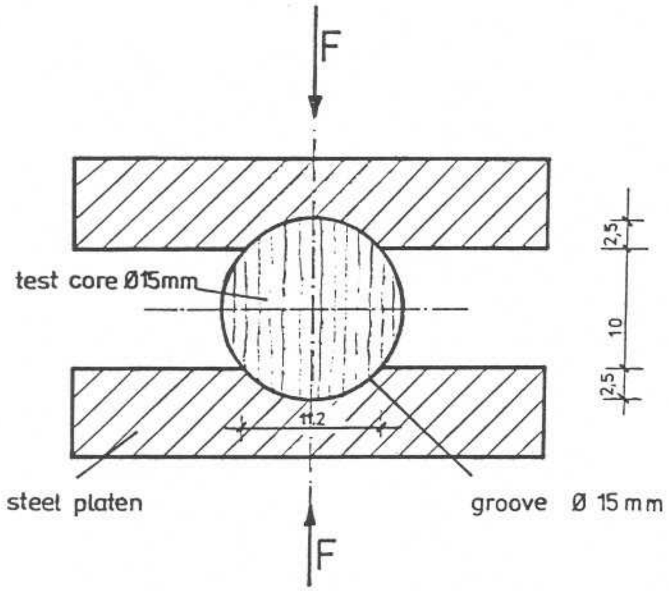


*Fig. 1. Principle of the testing of timber cores*

referred to as $\sigma_{NP}$), which hitherto have been normally used for strength investigations and tests according to ref. 2.

The initial findings and information as published in ref. 3, have been further deepened and emphasized by a great number of new studies and investigations.

### Test core method

Based on a thorough and careful analysis of the present state of development in the field of non-destructive and low-destructive testing methods and procedures, the authors have decided on the application of the test core method. The simple practical management and handling of this method is connected with a relatively small technical expenditure in terms of equipment and appliances. In addition, to determine the strength, other properties and parameters may also be determined directly, i.e. the bulk density or volume weight, the moisture of timber, ref. 2, the pH value, the check of aggressive media and the flexural strength by adopting the Dynstat-type method, ref. 4.

The drill holes resulting from the sampling of test cores can be put back again immediately. In spite of these positive characteristics and features, the method has only seldom been applied for determining strength, refs. 3, 5–7.

## Tests and experiments

### Applicability tests concerning the test core method

Initial studies and investigations are covering

- the definition of the geometry of test cores
- the development of a suitable testing device
- the determination of the number of samples required.

The test core diameter to be selected should be such that the smallest possible reduction of cross section will result. On the other hand, however, an adequate size should ensure a timber structure being approximately equal to that of the standard test specimens.

25–40 mm have proved to be well suited for the investigations. Tests performed by using test cores with a diameter of 10 mm have produced similar results. The experimentally used testing device is shown in Fig. 1.

In accordance with the minimum quantity of samples as required in ref. 2, the number of test specimens was defined to be 25 per test series.

### Test procedure

All samples have been treated by subjecting them to a standard climate, with a temperature of 25°C and a relative air humidity of 65% so that the moisture of timber was 12% with all specimens.

The test cores and standard test specimens were sampled by the authors from timber discs next to each other. The tests have been performed by using a ZD 20 type tension–compression testing machine. The determination covered the failure load. With a great number of test specimens, the load–deformation diagram has been recorded and plotted as well.

Prior to testing the strength, the bulk density of each test specimen was determined according to ref. 2. The documentation and evaluation have been implemented in a computerized way. The tests and experiments were initially performed by using new timber, oak, beech, spruce.

The subsequently tested old timber specimens have been sampled by the authors from square timber of building constructions with an age ranging from 60 to 200 years.

## Results and findings

The results and findings of 1324 tests, Table 1, were obtained from a total number of 23 test series performed by means of test cores (with a diameter of 15 mm) and of standard test specimens (sized 20×20×30 mm).

### Tests using new timber

The tests performed by means of 3 series using oak, beech and spruce timber, demonstrated that with test cores, a clearly discernible failure is occurring. A failure pattern is being produced resembling that of the standard test specimens. Some typical examples are illustrated by Fig. 2, refs 5, 8.

A comparison of the mean values of the strengths determined by using test cores, with those values determined by means of standard test specimens, shows that the ratio of the quotients of $\sigma_{BK}/\sigma_{NP}$ amounts to 1.18, 1.01, 1.25 for oak, beech and spruce timber, respectively. The scatterings are 8% for oak, 15% for beech, and 12% for spruce.

Analogous ratios were also obtained with regard to the bulk densities (hereinafter referred to as $\rho_{BK}$ for the test cores and as $\rho_{NP}$ for the standard test specimens, respectively) of the investigated series. A comparison of the 5%-quantities is producing approximately equal results. The average quotient for all three kinds of timber is 1.1.

### Tests using old timber

- Pine timber

The investigation included 11 series with pine-timber

***Table 1. Summary of the test results and findings***

| Test group | Series | Kind of timber | Age | n | $\sigma_{BK}$ (N/mm²) | $\rho_{BK}$ (kN/m³) | n | $\sigma_{NP}$ (N/mm²) | $\rho_{NP}$ (kN/m³) | $\sigma_{BK}/\sigma_{NP}$ (–) | $\rho_{BK}/\rho_{NP}$ (–) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | oak | new | 25 | 49.92 | 6.80 | 25 | 42.43 | 6.17 | 1.18 | 1.10 |
| | 2 | beech | new | 25 | 58.88 | 6.94 | 25 | 58.12 | 7.33 | 1.01 | 0.95 |
| | 3 | spruce | new | 25 | 3.11 | 3.94 | 25 | 24.87 | 3.48 | 1.25 | 1.13 |
| I | 4 | pine | 60 | 48 | 50.55 | 4.35 | 17 | 44.32 | 4.49 | 1.14 | 0.97 |
| | 5 | pine | 60 | 25 | 49.84 | 5.42 | 25 | 66.23 | 5.22 | 1.08 | 1.04 |
| | 6 | pine | 70 | 43 | 43.96 | 5.16 | 25 | 39.68 | 5.10 | 1.11 | 1.01 |
| | 7 | pine | 70 | 54 | 60.56 | 6.26 | 132 | 62.04 | 6.18 | 0.98 | 1.01 |
| | 8 | pine | 70 | 28 | 53.47 | 4.24 | 27 | 49.03 | 4.24 | 1.09 | 1.00 |
| | 9 | pine | 140 | 16 | 60.89 | 5.82 | 25 | 60.59 | 5.42 | 1.00 | 1.07 |
| | 10 | pine | 140 | 25 | 51.11 | 5.06 | 25 | 50.87 | 5.01 | 1.00 | 1.01 |
| | 11 | pine | 208 | 35 | 43.13 | 4.74 | 50 | 43.28 | 4.36 | 1.00 | 1.09 |
| II | 12 | spruce | 138 | 22 | 46.53 | 4.37 | 36 | 40.48 | 40.75 | 1.14 | 1.07 |
| | 13 | oak | 138 | 20 | 5.53 | 6.68 | 21 | 53.80 | 0.65 | 1.03 | 1.03 |
| | 14 | oak | 140 | 32 | 54.85 | 0.71 | 50 | 54.40 | 6.06 | 1.01 | 1.17 |
| | 15 | pine | 60 | 25 | 5.68 | 6.65 | 20 | 50.56 | 6.04 | 1.12 | 1.10 |
| | 16 | pine | 60 | 25 | 50.61 | 5.26 | 20 | 49.45 | 5.05 | 1.02 | 1.04 |
| | 17 | pine | 60 | 25 | 50.45 | 5.26 | 20 | 47.65 | 5.58 | 1.06 | 0.94 |
| | 18 | pine | 60 | 25 | 46.09 | 5.37 | 20 | 54.01 | 5.19 | 0.85 | 1.04 |
| III | 19 | pine | 60 | 25 | 50.95 | 4.96 | 20 | 48.00 | 4.76 | 1.05 | 1.04 |
| | 20 | pine | 60 | 25 | 5.41 | 0.55 | 20 | 54.87 | 5.33 | 0.99 | 1.03 |
| | 21 | pine | 60 | 25 | 5.02 | 5.61 | 20 | 51.60 | 5.30 | 0.97 | 1.06 |
| | 22 | pine | 60 | 25 | 48.13 | 5.71 | 20 | 54.37 | 5.37 | 0.89 | 1.06 |
| | 23 | pine | 60 | 23 | 50.57 | 5.30 | 20 | 61.74 | 5.24 | 0.82 | 1.01 |

(service life) of 60 years. In this case, the ratios of the strength values and the bulk density are ranging between 0.84–1.12 (concerning the series 4, 5 and 15 to 23 according to Table 1), so that the same results and findings as the new timber were identified. Also, the 3 test series performed with structural timber being 70 years old and the 3 series for structural timber being 140 or 200 years old, were producing analogous results.

- Spruce timber

Spruce timber which has been built in about 140 years ago, produced similar quotients (being 1.14 and 1.07, respectively) for the strength and for the bulk density.

- Oak timber

The tests covered two series using oak with an age of 140 years, which were showing quotient values as follows:

$$\sigma_{BK}/\sigma_{NP}=1.03 \text{ and } \sigma_{BK}/\sigma_{NP}=1.01$$

The strength values of old oak are within the range of the values applying to new oak (oak=52, beech=60, spruce=40, pine=40 N/mm² according to ref. 9.

## Result of a regression analysis

The linear regression analysis according to refs. 10 and 11 was accomplished for the mean values of the strength and bulk density. Fig. 3 illustrates the correlation between the compression strengths depending on the number of the test series.

The ratio of the strength of the test cores to the strength of the standard test specimens approximates to

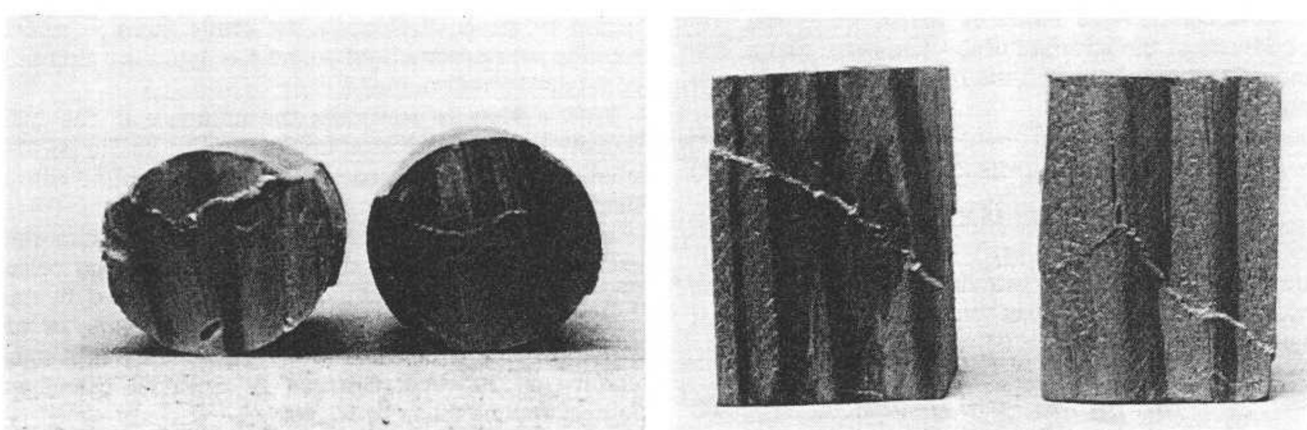

***Fig. 2. Typical failure patterns for test cores (diameter of 15 mm) and standard test specimens***

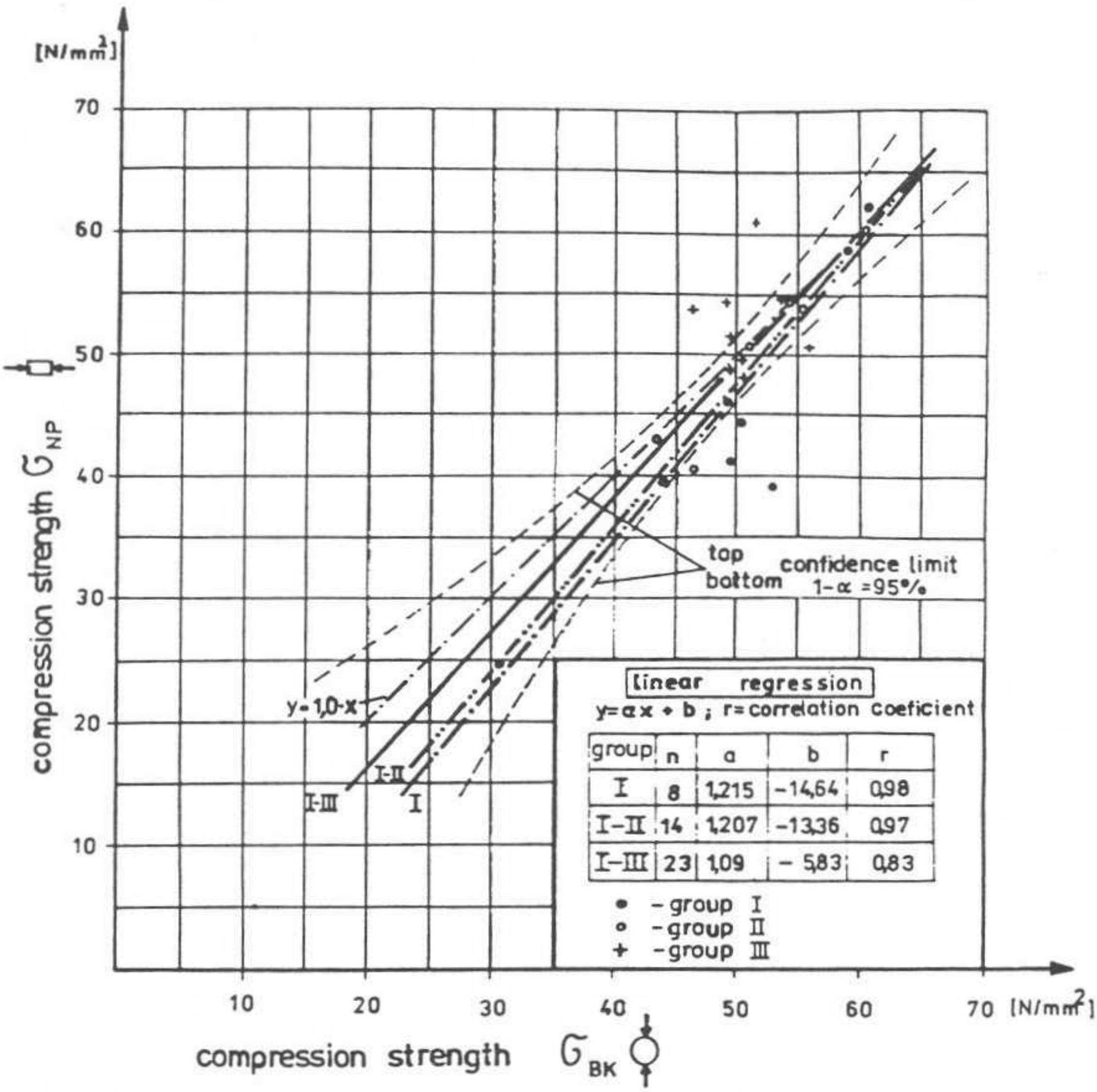


*Fig. 3. Comparison of the compression strength of the test cores with the compression strength of standard test specimens*

the value of 1/0.97=1.03 with an increasing number of test series (see Fig. 4).

The simplified conversion formula reading

$$\sigma_{BK}=1.0\ \sigma_{NP} \quad (1)$$

is within the confidence limit of 95% (see Fig. 4). Concerning the pine-timber specimens sampled from structural components being 60 to 200 years old, the dependence of the strength of the test cores and of the standard test specimens on the bulk density (see Fig. 5) is obtained as follows:

$$\sigma_{BK}=4.12\times\rho_{BK}+29.21\ \ (r=0.51) \quad (2)$$

$$\sigma_{NP}=6.66\times\rho_{NP}+16.65\ \ (r=0.54) \quad (3)$$

The bulk density of the standard test specimens is obtained from bulk density of the test cores by means of the equation

$$\rho_{NP}=0.9\times\rho_{BK}+0.33\ \ (r=0.94) \quad (4)$$

Within the confidence limit of 95%, the simplified formula (see Fig. 6) is sufficient and reads as follows:

$$\rho_{NP}=0.9\times\rho_{BK} \quad (5)$$

A comparison of the dependence of the strength on the bulk density for old timber with that applying to new timber is verifying that old timber has no less strength than new timber (see Fig. 6).

A decrease in strength of timber having been subjected to stress and strain for many years – which hitherto was assumed for sound (i.e. faultless) timber – could not be determined.

With a view to recording the influence of the bulk density on the regression line (according to Fig. 4), the quotients of $\rho_{BK}/\rho_{NP}-\sigma_{BK}/\sigma_{NP}$ have been plotted into a diagram (see Fig. 7).

In addition to this, the frequency distributions and normal distributions of the quotients are being calculated. With a direct influence being exercised by the quotients of the bulk density on the quotients of the strength, the gradient of the regression line ought to be about 1.0. However, instead of this the calculated regression line reads as follows:

$$\sigma_{BK}/\sigma_{NP}=0.36\times\rho_{BK}/\rho_{NP}+0.66\ \ (r=0.20) \quad (6)$$

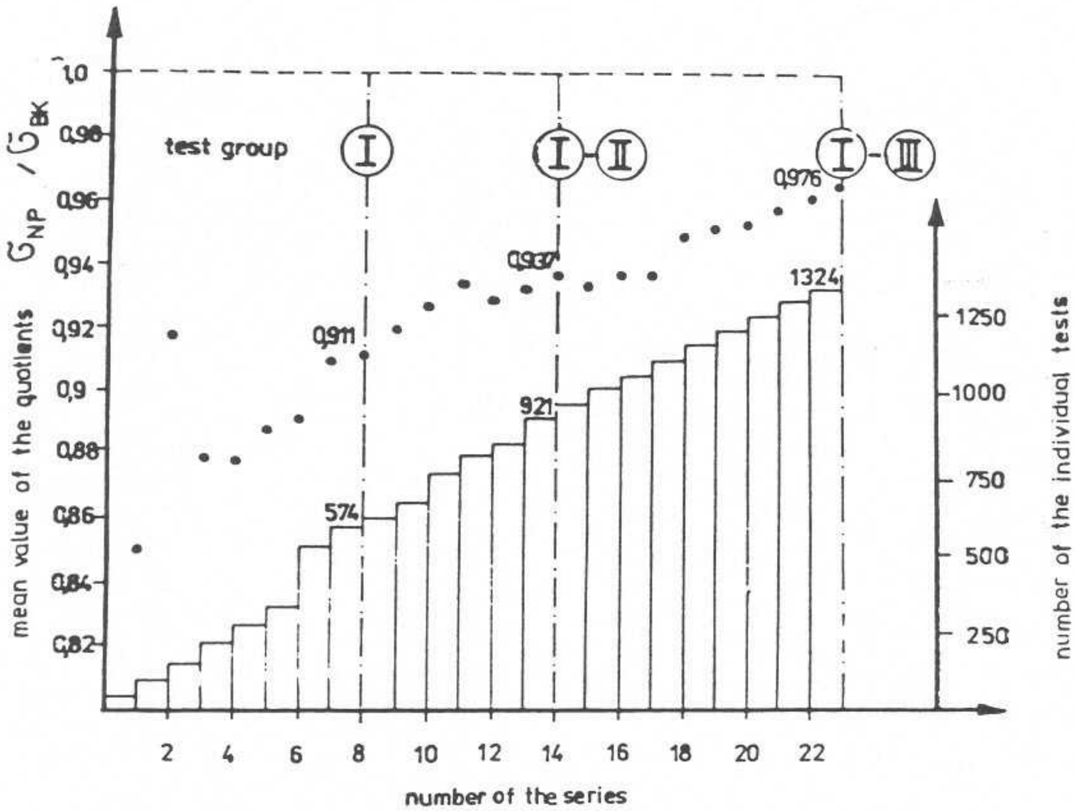


*Fig. 4. The quotient $\sigma_{NP}/\sigma_{BK}$ depending on the number of the test series*

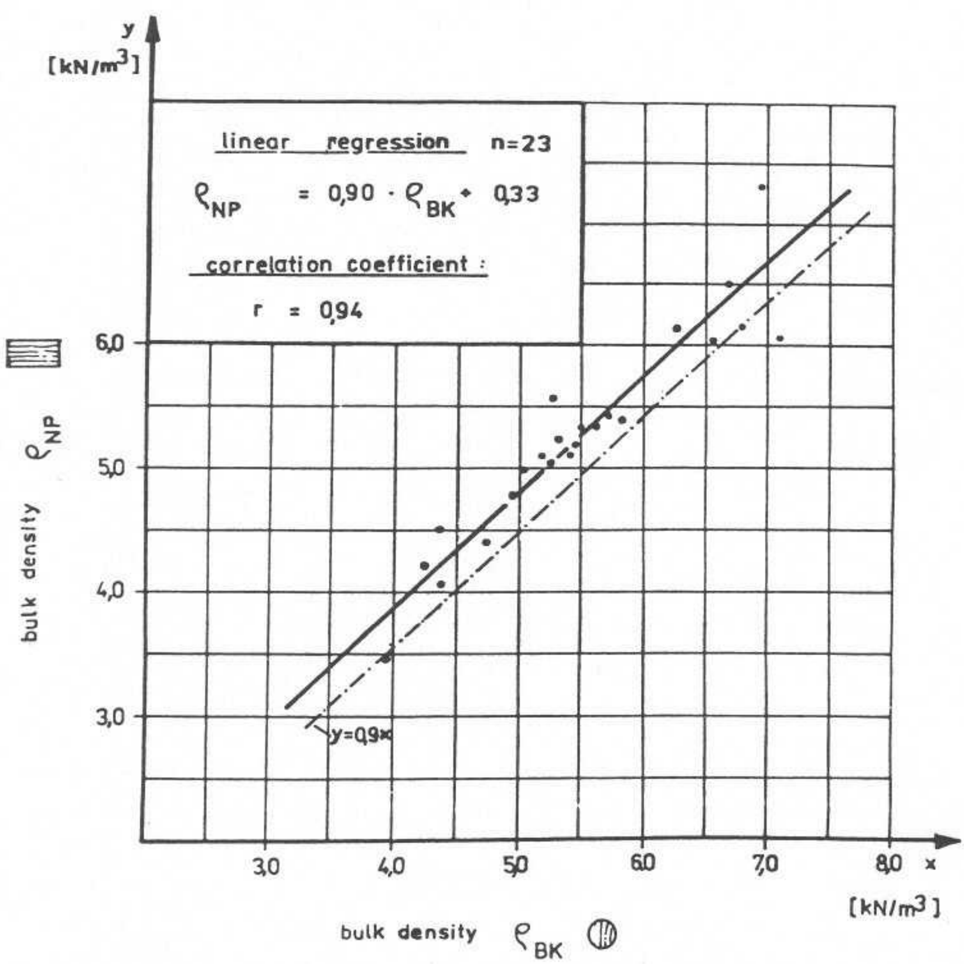


*Fig. 5. Comparison of the bulk density of the test cores with the bulk density of th specimens*

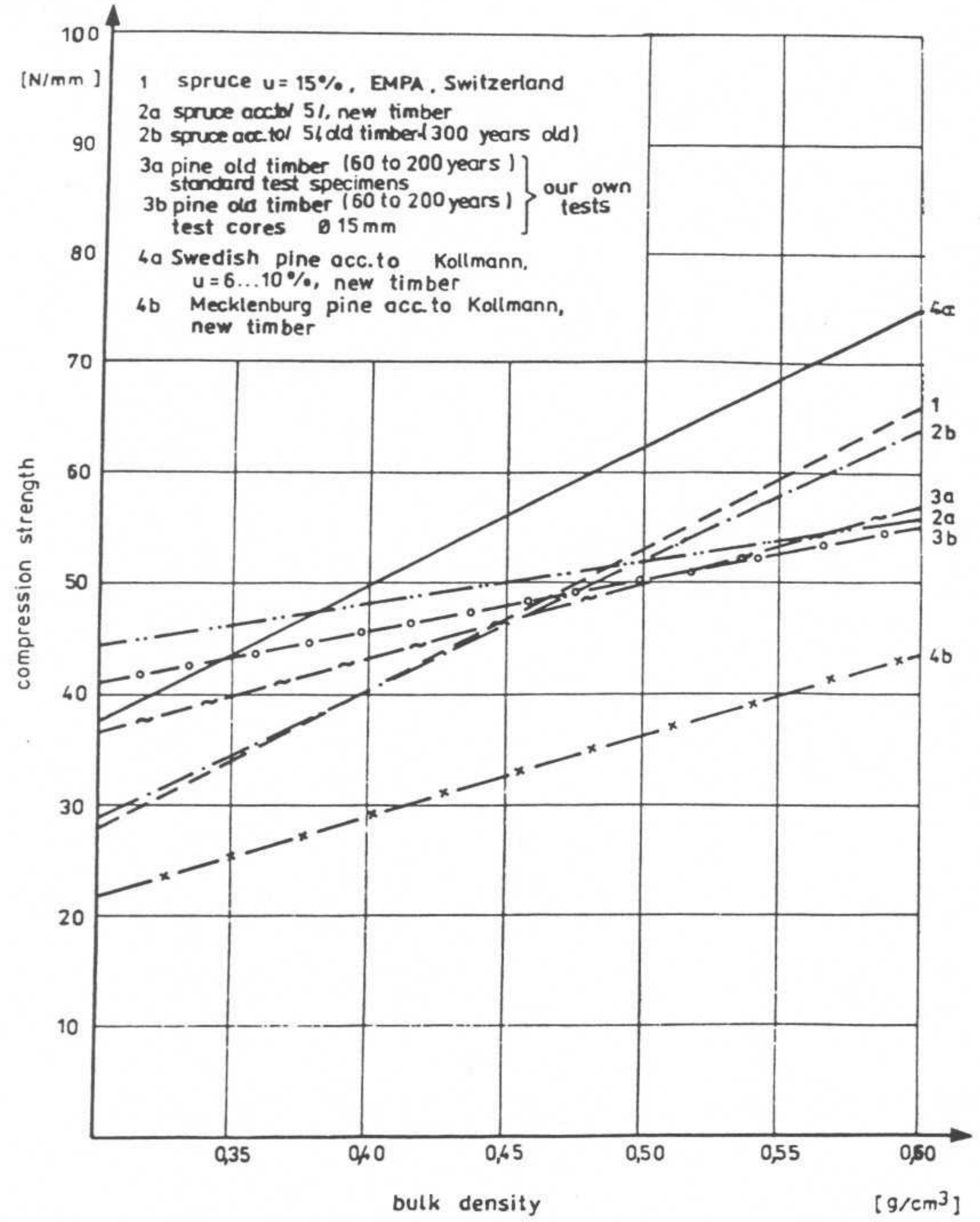


*Fig. 6. Compression strength parallel to the grain depending on the bulk density for new timber and old timber*

This line is considerably deviating from the ideal line. Thus, the strength of the test cores being somewhat higher cannot fully be explained by the determined bulk density being higher as well.

## Summary of the results and findings

The high linear defineability of the compression strength of the standard test specimens by means of the strength of test cores with a diameter of 15 mm verifies the test core method for determining the compression strength parallel to the grain.

Thus, the test core method is well suited to determine in situ the strength of built-in timber.

A number of other studies and investigations can be accomplished by using test cores as well.

An expected decrease in strength with old timber could not be observed. The high correlation between the bulk density and the strength enables the provision of quantitative data and particulars concerning the strength by the application of non-destructive methods and procedures for measuring the bulk density.

Studies and investigations to be accomplished in the future will be focused on the following principal aspects and topics:

- development of a data basis concerning all investigations into the strength of old timber
- determination of partial safety factors for the calculation (design) of old timber construction.

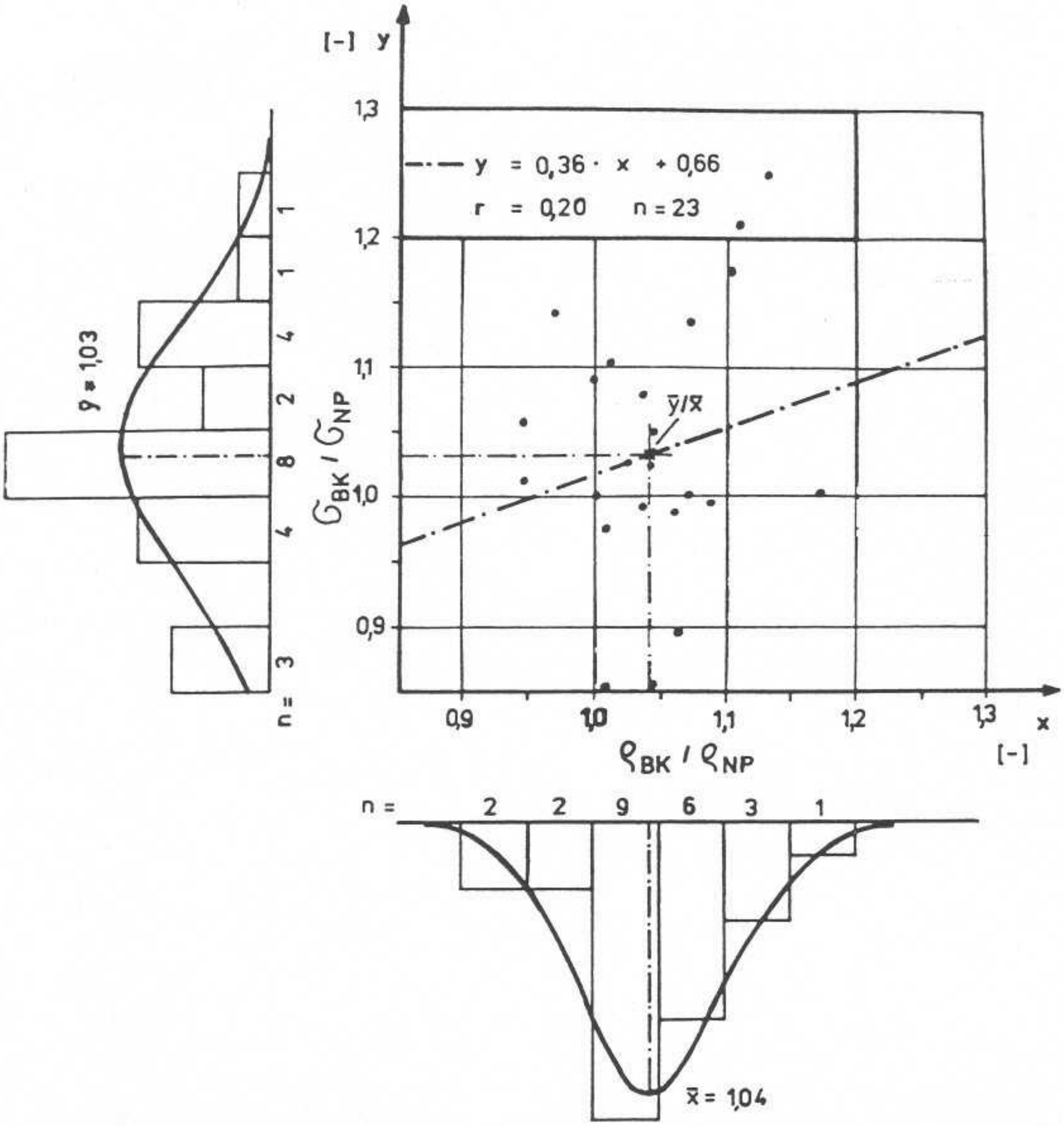


*Fig. 7. Linear regression, frequency and normal distribution of the quotients $\sigma_{BK}/\sigma_{NP}$ and $\rho_{BK}/\rho_{NP}$*

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