Conserving and strengthening prestressed concrete structures

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Conserving and Strengthening Prestressed Concrete Structures

Conservation et réhabilitation de structures en béton précontraint

Erhalten und Ertüchtigen von Spannbetonkonstruktionen

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SUMMARY

Conserving and strengthening civil structures offers a multitude of interesting engineering tasks extending from material technology, non-destructive testing and designing up to execution. The various steps involved are explained fully by way of an example of a prestressed concrete bridge. In conclusion, questions of cost effectiveness and decision aids are discussed and mention is made of quality assurance and control systems; even questions relating to insurance have not been left out of consideration.

RÉSUMÉ

La conservation et la réhabilitation d'ouvrages en béton précontraint est un domaine qui embrasse des activités d'ingénierie variées et intéressantes, allant de la technologie des matériaux, des essais non destructifs, de l'étude jusqu'à la réalisation. Les différentes étapes sont mises en évidence à partir de l'exemple d'un pont en béton précontraint. Les questions de rentabilité et les aides de décision sont ensuite discutées et les systèmes de contrôle et d'assurance de la qualité sont examinés. Les problèmes d'assurance sont évoqués également.

ZUSAMMENFASSUNG

Die Erhaltung und Ertüchtigung von Bauwerken bietet eine Vielzahl interessanter Ingenieuraufgaben. Sie reicht über die Baustofftechnologie, den zerstörungsfreien Prüfverfahren und den konstruktiven Bereich bis hin zur Ausführung. Am Beispiel einer Spannbetonbrücke werden die verschiedenen Schritte durchgängig erläutert. Abschliessend werden Wirtschaftlichkeitsfragen und Entscheidungshilfen diskutiert und Qualitätssicherungs- und Überwachungssysteme angesprochen; selbst Versicherungsfragen bleiben nicht unberücksichtigt.

1. STRENGTHENING - AN ENGINEERING TASK WHICH IS GAINING SIGNIFICANCE

The recession in the quantitative growth of the civil engineering market is followed by improvements in quality. The number of interesting, outstanding engineering tasks required for above ground structures is shifting to sub soil structures. Activities in the field of environmental technology - air, water, ground, noise - and renovation of existing buildings are gaining in significance. There is an increasing requirement to conserve and strengthen existing structures. It is estimated that annually expenses between 1 and 2 % of the value of the new structures will have to be invested in rehabilitation work.

Strengthening may be required

- due to higher loading or higher safety requirements
- due to deterioration of loadbearing capacity stemming from aging or structural deficiencies.

The approach in both cases is the same.

Tackling the problem in detail shows very quickly that a number of interesting engineering tasks are involved, related to construction material technology, non-destructive testing, design, execution and inspection.

Using the Gänstor prestressed concrete bridge in Ulm as an example for strengthening, the tasks involved are explained and further typical applications are illustrated.

2. BRIDGE SYSTEM

Just before the end of the war all of the bridges over the Danube in the City of Ulm were destroyed; the Gänstor bridge was reconstructed in 1947 as a prestressed concrete hinged frame structure /1/ Fig. 1).

In the course of modernizing the traffic system in downtown Ulm during the early 80s the bridge was inspected by the design office of Prof. Leonhardt and subsequent strengthening was planned and executed in 1984.

3. LOCATING DAMAGES (DIAGNOSIS)

There are numerous ways of preparing a diagnosis on the basis of testing methods as far as possible non-destructive (non-destructive testing method ZfP, /2/) sometimes involving sampling according to the small-step principle (e.g. when deficiencies are discovered during a rough control, the investigation is intensified). Some of these procedures are specified in the German Standard DIN 1076 "Monitoring and Testing Engineering Structures". The following lists the various possibilities (for details see /3/) for locating damage:

- Crack observation (restraint, static-dynamic, e.g. use of glass strips)
- Assessment of bearings, joints, waterproofing, drainage
- Tracing efflorescence
- Spalling of concrete (e.g. due to alternating freezing and thawing in conjunction with de-icing salts) or due to corrosion products
- Tracing corrosion streaks
- Measuring concrete cover and carbonation
- Testing chloride contamination

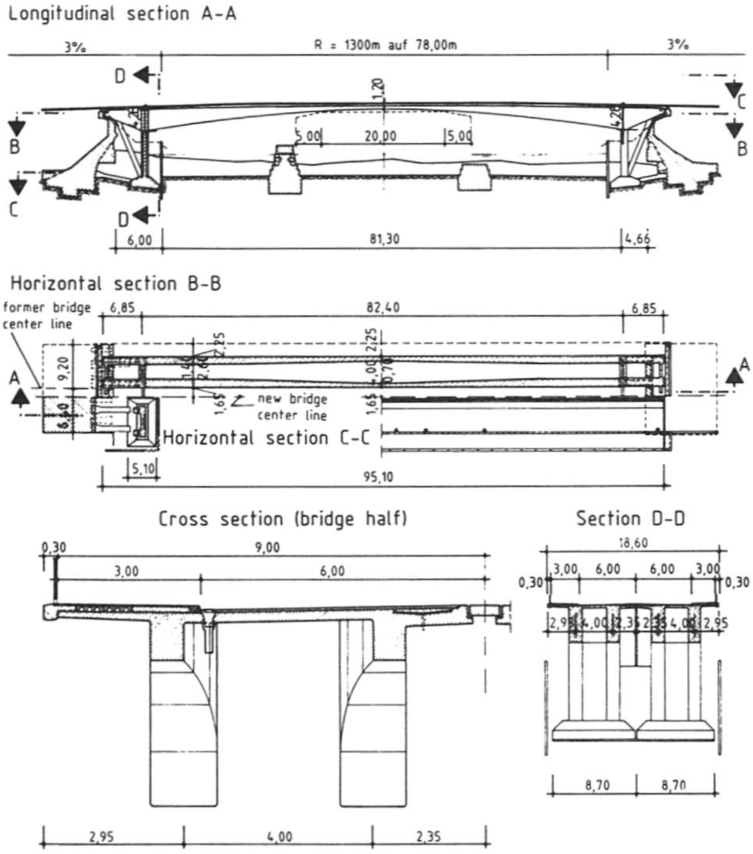


Fig. 1 Gänstor Bridge Ulm

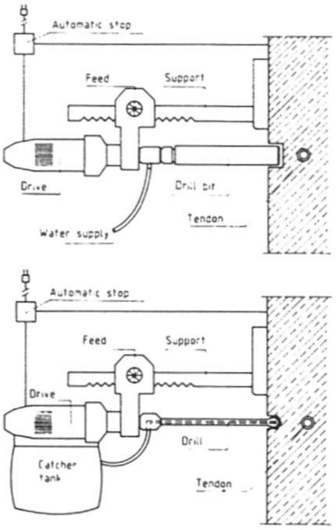


Fig. 2 Sensitive Drilling Technique

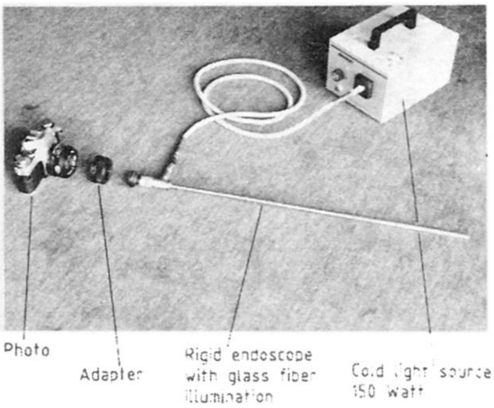


Fig. 3 Endoscope

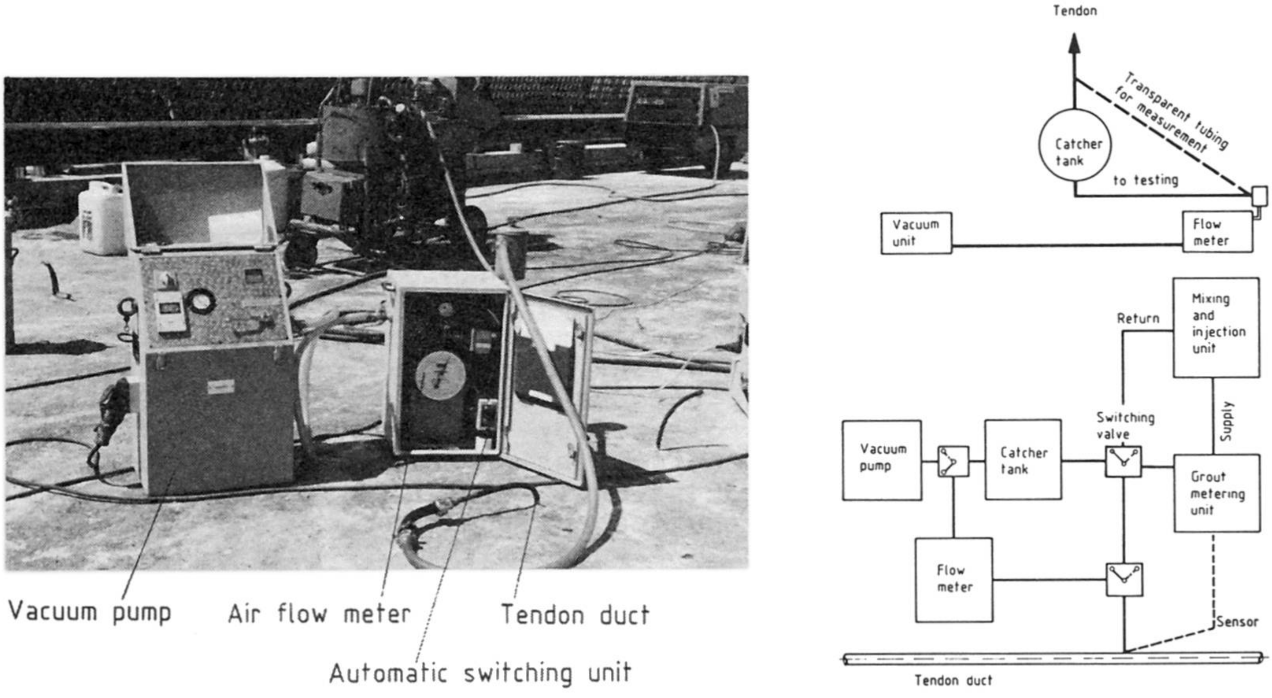


Fig. 4 Vacuum Method, Cavity Sensing, Grout Measurement

- Potential measurements for detecting corrosion (not always explicit)
- Observing the marginal conditions for corrosion (moisture etc.)
- Probe drilling for detecting non-grouted tendon ducts (detecting tendons by means of equipment and drawings; careful drilling technique with automatic drill stop, at weak locations of the system endoscopic analysis often useful; documenting results is good practice).
  (Figs. 2, 3)
- Detecting cavities by the vacuum method (highly accurate indication, drying possible for later rehabilitation)
  (Fig. 4)
- Gamma radiography (for establishing the grouting condition and tendon rupture; expensive, max. area 30 x 40 cm)
  (Figs. 5a and b)
- Ultrasonic analysis (assessing grouting condition and fracture, possible only for bars; used in establishing major concrete voids)
- Tendon sampling for establishing possible damage (Fig. 6)
- Concrete sampling to establish its strength (usually post-curing to a major extent)
- Vibration analysis (observation of the response spectrum of an excited structure as a function of time, prerequisite: system responding to vibration, changes must be relatively large)
  (Figs. 7, 8 - see also para 7).

4. DETERMINING LOADBEARING BEHAVIOUR (ANAMNESIS, ANALYSIS) /3/

4.1 Material Properties

To establish the loadbearing behaviour it is necessary to be aware of the long-term behaviour of the damaged materials, particularly in regards to the fatigue strength of the damaged tendons (Fig. 6). Concrete usually demonstrates sufficient compressive strength due to post-hardening.

Usually it will be necessary to establish upper and lower probability limits, since sampling analysis and limited testing methods leave in gray zones. For instance, on the basis of the analysis of the Gänstor bridge (para 3) taking into account the successful experience in the rehabilitation of non-grouted tendons, the procedures as shown in Table 1 were established.

4.2 Loadbearing Behaviour

Using this information as regards the material aspects and the, for instance, more realistically assessed newly established live loading actions caused by traffic etc. the load effects in the structure can be established and compared to the loadbearing capacity, taking into account the reserves of the system (transverse distribution) and analysing various, structurally possible systems (taking into account redistributions caused by cracking, plastic hinges etc.); this is then followed by calculating the stresses and the cracks widths under conditions of actual use and the safety factors in the calculated conditions of failure. In this way, it is possible to approximate the loadbearing behavior and the effect of any strengthening which may be necessary.

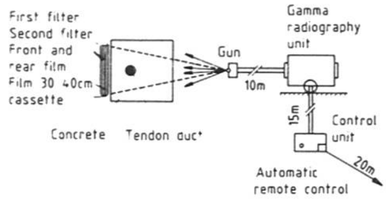


Fig. 5a Basic Principle of Gamma Radiography and Equipment Layout

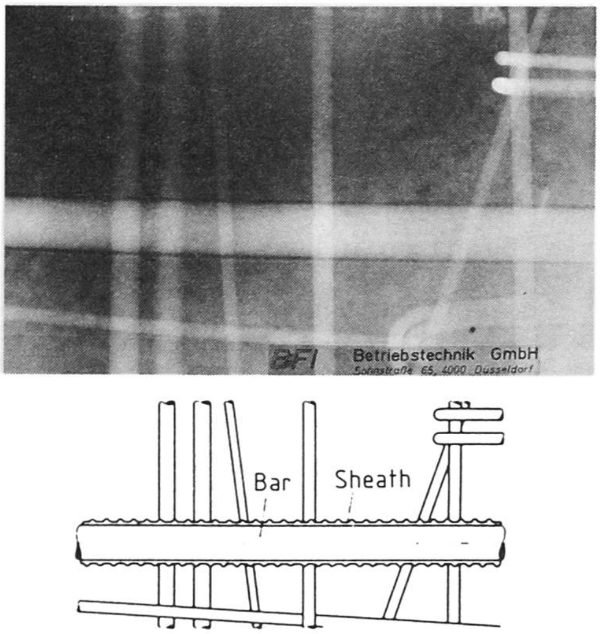


Fig. 5b X-ray Photograph, concrete thickness approx 25 cm, cobalt 60. (photo: Betriebsforschungsinstitut Düsseldorf)

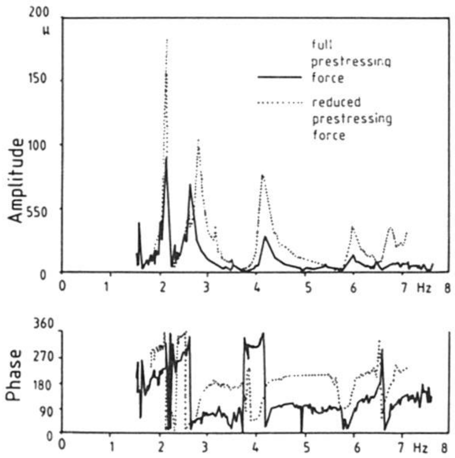


Fig. 8 Change of Frequency in the Bridge System as per Fig. 7
Before and After Tendon Strengthening

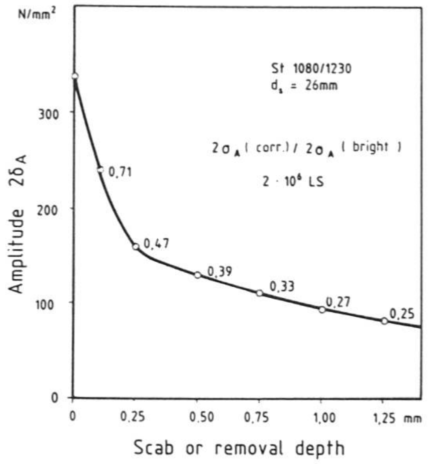


Fig. 6 Influence of Corrosion Scab on Fatigue Strength (26 mm dia St 1080/1230) /3/

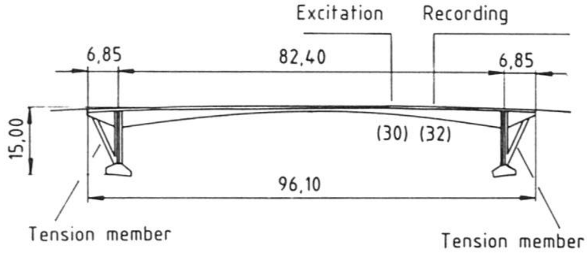


Fig. 7 Vibration System of Gänstor Bridge, on which Vibration Analysis was carried out according to Fig. 8

	upper limit	lower limit
30 % to 40 % of tendons well grouted	40,0	30,0
10 % tendons permit post-activation	10,0	10,0
25 % tendon ducts with 100 % or 80 % successful post-grouting	25,0	20,0
25 % or 35 % not permitting grouting. Failure after e.g. 50 years by half or fully	12,5	0
Further system reserves 0 or 5 %	5,0	0
Remaining stress after 50 years in %	92,5	60,0
Necessary strengthening for e.g. ultimate strength to reattain 100 %	7,5	40,0
	100,0 %	100,0 %

Table 1 Choice of Upper and Lower Limits for Tendon Condition

4.3 Failure Probabilities

Fig. 9 shows failure probabilities as a function of time for specific damage condition, taking into account the failure rates of non-grouted and post-grouted tendons. This clearly shows the influence of the statistical distribution of the influencing variables. This illustrative representation enables the engineer to make a decision as to whether simple rehabilitation is sufficient, whether it is good practice to downgrade the bridge, whether the structure has still sufficient stability for a limited period (as regards the Gänstor bridge new traffic planning is scheduled in 20 years which could result in the bridge being superfluous) or whether the structure needs reinforcing or strengthening.

5. POSSIBILITIES OF STRENGTHENING STRUCTURES (THERAPY)

5.1 General

The following procedures have a proven record of success for strengthening:

- additional tendons designed to take bending and shear (necessitating low-slip anchorages)
- reinforced or prestressed concrete strengthening (for both positive and firm bonding) as well as
- bonded steel straps

The danger of non-grouted tendons forcing their way out must be taken into account /3/. Thinking in terms of truss models helps in creating clear understanding of the load bearing mechanisms (Fig. 10). By way of an example, Fig. 11 shows strengthening of a column by means of shotcrete and precast concrete components and Fig. 12 strengthening of a beam element. Fig. 13 shows various connecting details for handling tensile forces. The profile of the bond stresses in the bonded joints of freshly bonded steel straps /4/ can be seen from Fig. 14. Strengthening with freely guided longitudinal prestressing is shown in Fig. 15. Fig. 16 relates to strengthening by exterior prestressing reinforcement /5/. A washed out foundation was placed on newly produced slurry walls using prestressed concrete sleeves (Fig. 17).

It is often sufficient to carry out simple therapies by competent professionals:

- sealing, coatings to fill out cracks
- crack grouting (Fig. 18); particular requirements must be observed when grouting coupling joints
- repairing corrosion locations
- vacuum grouting, using specially formulated resins, if need be (Table 2) in wet ducts (high specific weight, water displacing, high consolidation etc.).

In repairing corrosion locations the trend is returning from purely mechanical protection by plastics to alkaline corrosion protection by PCC systems. Corresponding requirements and suitability tests are being formulated, the important thing being that such systems are intercompatible.

Interesting developments are going on in the area of PC systems where extreme requirements exist such as high tensile strength, high resistance to chemicals, special thermal expansion, modulus of elasticity, thermal conductance and dynamic damping. Chemical construction materials are now able to satisfy practically every requirement when formulated correspondingly.

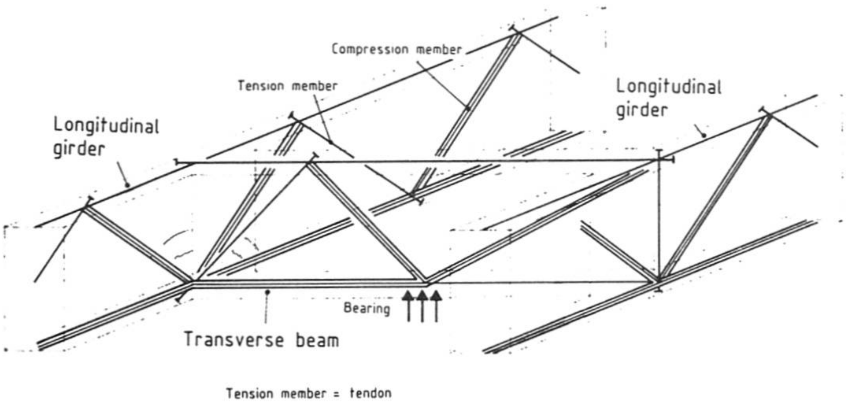


Fig. 10 Framework Analogy in Indirect Load Handling

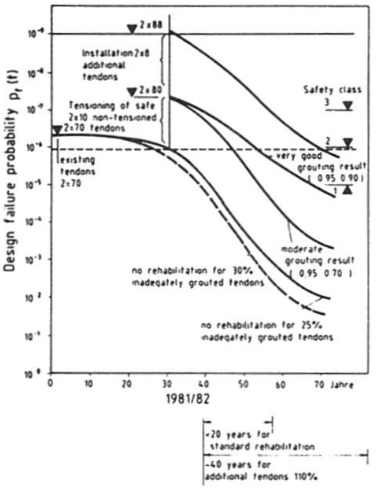
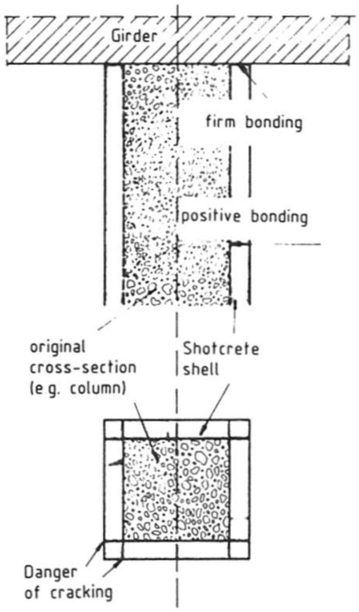


Fig. 9 Life Expectancy or Failure Probability on the Basis of the Assumptions made in Table 1 /3/



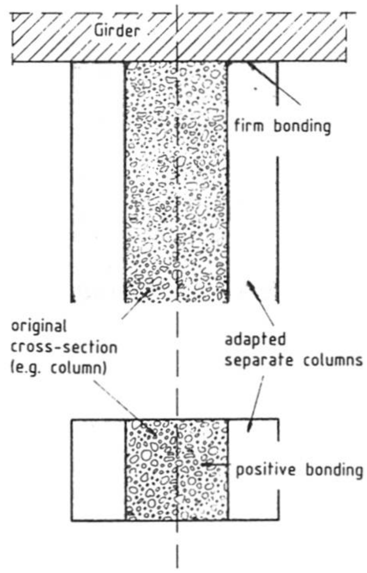


Fig. 11 Strengthening of a Column
a) using shotcrete
b) by adapted precast concrete components

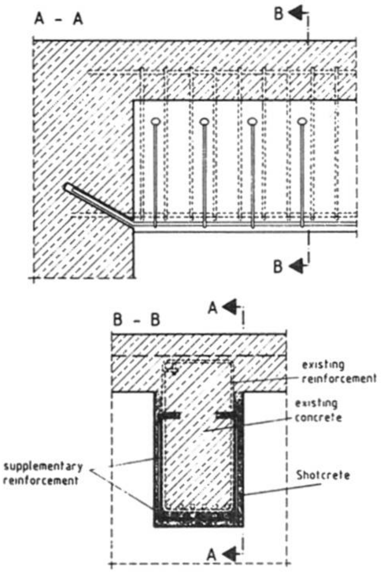


Fig. 12 Strengthening of a Bending Member Using Rebars and Shotcrete

In general a lot of detail knowledge has been gathered. To go into the details a separate paper /3/ would be necessary. Of late, rehabilitation extends up to subsequent cathodic corrosion protection.

5.2 Procedures for Strengthening the Gänstor Bridge

In accordance with the information provided in paragraphs 3 to 5.1 the following measures were deemed necessary:

a) Technological measures

- Reinstating the corrosion protection of the reinforcement (vacuum injection; grouting with special resins)
- Closing cracks
- Repairing corrosion spalling
- Coating of concrete (drying out neccessary because of chloride contamination), reinstating the surface, by pigmented epoxy resin coating
- Renewing the waterproofing and surfacing of the bridge (drying out because of chloride contamination).

b) Structural measures

The ten tendons originally intended to provide ultimate strength for each tension member required tensioning to improve the condition in use and to make up for the incurred creep and contraction losses. Two variants were investigated for the necessary further strengthening of the structure:

- strengthening by permanent anchors (Fig. 19) and
- strengthening by additional prestressed concrete and concrete elements (Fig. 20).

The solution using permanent anchors reduces the loadbearing capacity of the foundation and is thus limited in performance. The higher performance solution of prestressed concrete is, however, more expensive since the tension members need to be exposed down to the foundation located in ground water.

5.3 Cost Analysis, Decision Variants for the User

Fig. 21 shows the relationship between the performance of the various measures, the loss of safety due to penetrating investigation of the structure, and the costs, thus aiding the client in making a decision which, in the end, must also take into account further - and also political - criteria for the one or the other case. Lastly this must be the best solution as regards the overall cost effective considerations. A decision was made in favour of the permanent anchor solution.

5.4 Warranty, Insurance

In the building and construction trade in the Federal Republic of Germany the general terms of contract are usually anchored in the VOB contract procedures, covering erection of a non-deficient structure up to acceptance; within the warrenty period any remedial action necessary must be made or a reduction in price offered, or even damages paid. The conditions in other countries are similar. In work requiring repair only it is not always possible to pinpoint the cause for the damage in question. Should, for instance, a bar break in non-grouted tendons within the warranty period for carrying out the repair, it is not immediately clear whether the cause of the failure is due to poor repair work or whether the bar would have broken anyway.

Warranty should thus always only relate to the actual work carried out, particularly where repair work is involved. It is thus good practice to have the condition established prior to and following the repair work by recognized experts as testimony.

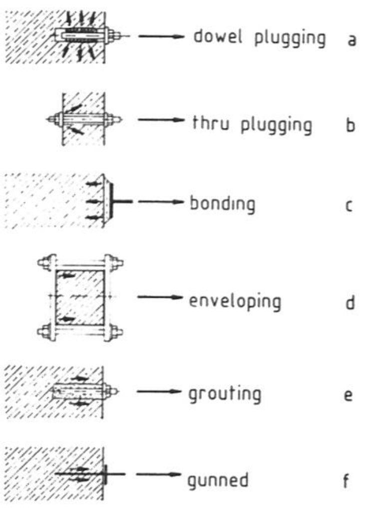


Fig. 13 Possiblities for Directing Tensile Forces into Existing Concrete

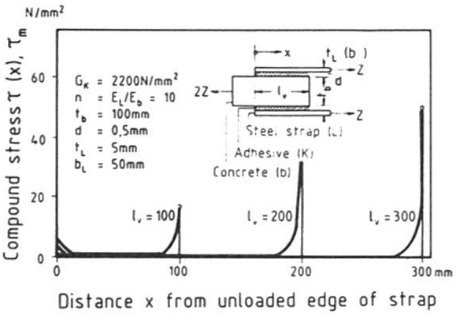


Fig. 14 Compound Stress Profile in the Bonded Joint of Bonded Steel Straps /4/

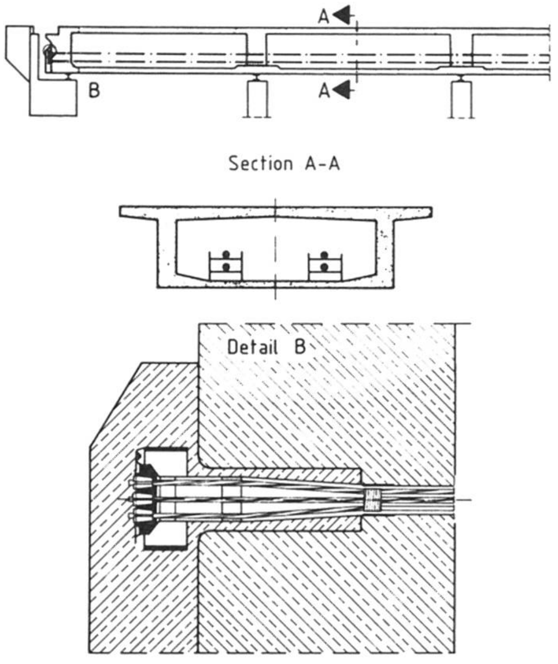


Fig. 15 Strengthening with Freely Guided Longitudinal Prestressing

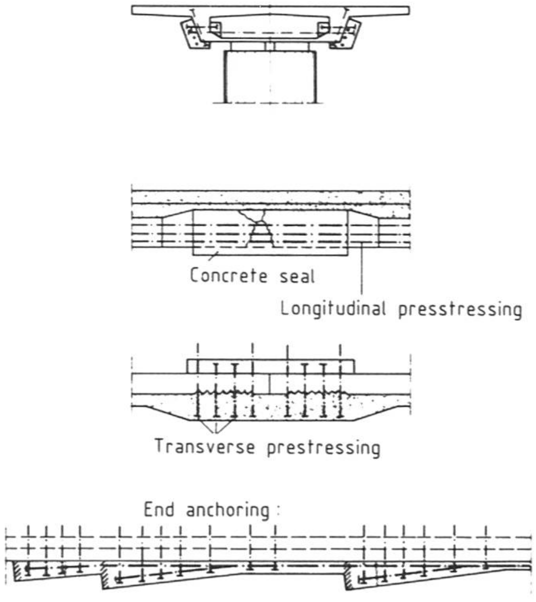


Fig. 16 Strengthening of a Hollow Box Girder with Exterior Prestressed Reinforcement in Site-Poured Concrete Straps (Prinzenallee)

Properties		DYWIPOX SPK
Pot life		
100 g/23 °C	h	3
Viscosity (rotation viscosimeter HAAKE)		
23 °C	m Pa s	830
15 °C	m Pa s	1500
10 °C	m Pa s	3380
5 °C	m Pa s	6030
Specific weight		
liquid	g/ml	1,75
solid	g/ml	1,81 - 1,87
Shore hardness A		
24 h dry		60
7 d dry		98
7 d wet		98
Glass transition temperature (German Standard DIN 53445)	°C	80
Capillary rising height		
0.02 mm dia	mm	20
0.083 mm dia	mm	10
0.84 mm dia	mm	3
pH value of excess water after 10 min.		9.00
	3 d	7.00 - 7.50
Adhesion property (continuous load 2 h)		
- wet	N/mm²	4.00 slip 0.027 - 0.037 mm
- dry	N/mm²	4.00 slip 0.025 - 0.035 mm
Adhesion property (ultimate load)		
- wet	N/mm²	7.60
- dry	N/mm²	11.40
Grout testing 6 m sheath 36 mm dia steel bar 26 mm dia water height 1 m		good creep, no water trapping, complete filling

Table 2 Specially Formulated Grouting Resin

Where the interaction between the existing structure and the repair work is exceptionally complicated, taking out insurances is recommended, here a distinction being made between the repair period and the subsequent warranty period. In some cases discussions must be held with the insurance people at an early date and the actual value, the current market value and the value of the new structure can be insured.

6. CONSTRUCTION EXECUTION

Quality assurance systems (QAS) are becoming more and more important /3/ in coming to grips with human failings in execution of the work. When the structure is already deficient particular care must be taken in proceeding with the rehabilitation or strengthening. Having to rehabilitate a rehabilitation is embarrassing. Tables 3 and 4 list the various QAS elements, without going into any depth. Checking the situation from the outside, non-destructively where possible, is important to generate pressure so that the QAS is taken seriously.

7. SUPERVISION after Commissioning

Damaged, rehabilitated or strengthened structures require particularly stringent, regular supervison for which important orientation aids are given, for instance, in German Standard DIN 1076 /7/. A promising development in this area is the so-called vibration analysis /3/ in which the structure or structural component is excited by vibration and the response measured. By comparing numerous responses received at different times, changes in the system can be observed. This method of vibration analysis was tested on the Gänstor bridge /6/. By simply changing the force of prestressing of the tension members by 6 % a significant change in the natural frequencies and the vibration profiles was observed (Figs. 7 and 8). In proper application cracks can also be detected by this method. It must also be checked to what extent the results obtained from a system responding relatively well to this analysis can also be anticipated from other bridge systems.
Using vibration analysis in assisting supervision of bridges requires the zero condition of the bridges to be established by measurement as soon as the structure is completed. Proper application is also only possible when the effects of changes in the system on the response having no influence on the loadbearing capacity (e.g. temperature and moisture) are known.

1. Introduction
2. Quality assurance program
3. Organization
4. Documentation
5. Design
6. Procurement
7. Material control
8. Process control
9. Inspection
10. Procedures where deviations exist
11. Remedial action
12. Documentation
13. Quality audit

Table 3 Procedures for Improving Quality /3/

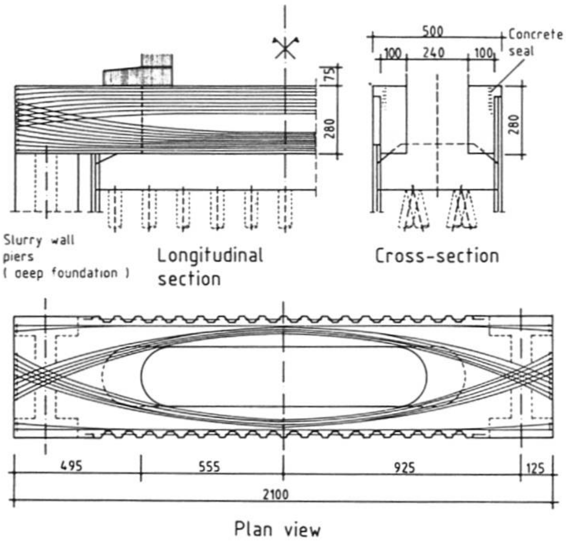


Fig. 17 Foundation Strengthening on the Bridge over the Danube at Dingolfing

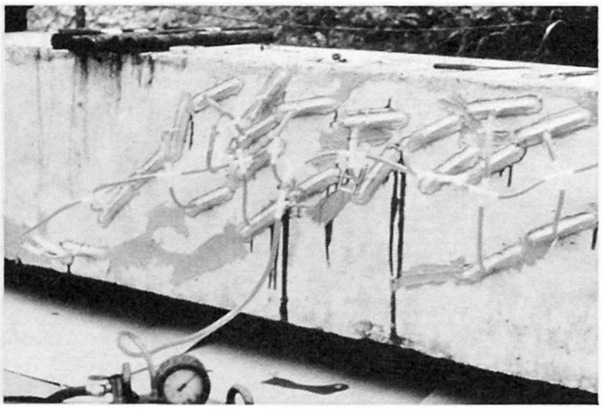


Fig. 18 Example of Crack Grouting

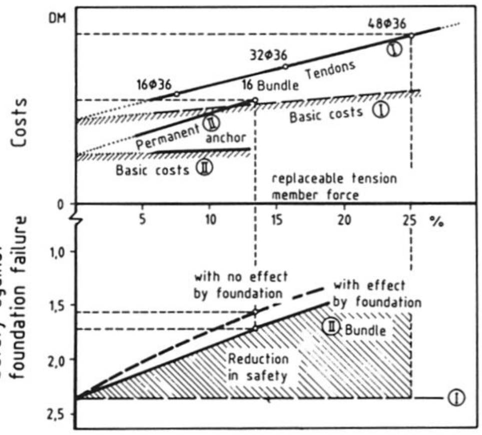


Fig. 21 Impact of Safety Against Foundation Failure on Repair Costs

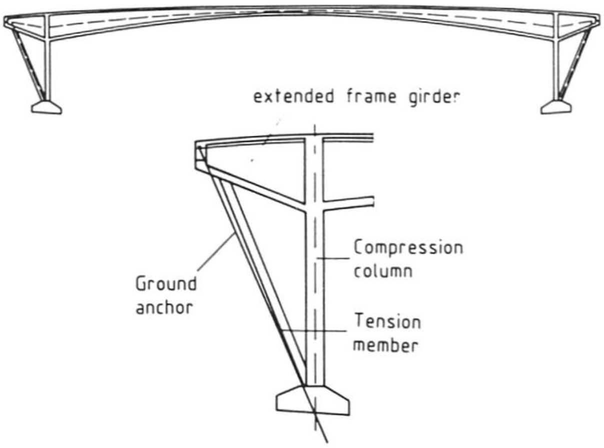


Fig. 19 Strengthening by Exterior Tension Members

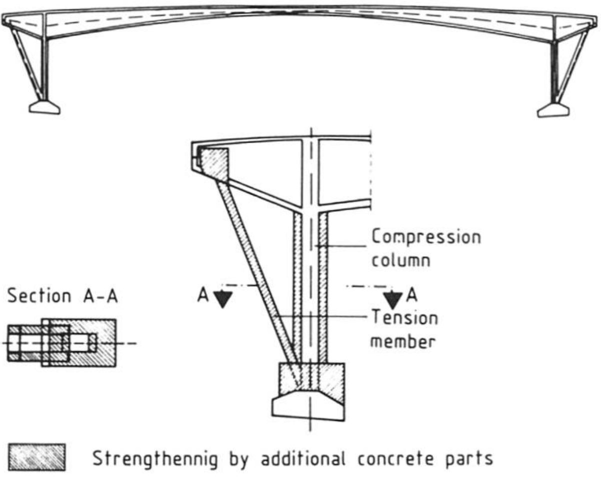


Fig. 20 Strengthening by Adapted Concrete Components

- Quality awareness
- Motivation
- Planning - more time
  - transparent
  - system reserves
  - safety plans
- Training and further education (check lists)
- Defining responsibility (internally and externally)
- In-house and outside quality control
- Provision measure
- Extension of warranty by assurance

Table 4 Breakdown of Quality Assurance Elements According to the IAEA Code /3/

8. CONCLUSION

Recognizing (actual condition) and remedying damage (strengthening) must be appreciated as a single unit. Effective and controlled remedial treatment of damage is only possible when the causes and extent of the damage are known. Finding this out as early as possible can help in minimizing the expense of repair.
The object of all supervision must be early recognition, i.e. damages must be detected at a time when they need not be urgently eliminated at the same time. In this way early recognition produces an overall picture of the condition of the respective structure and permits long-term, effective planning of the costs involved.
The necessary strengthening or repair measures can then be pinpointed in keeping with available funding and the technical priorities resulting from the investigation, both in terms of time and money. This, last but not least, also helps in obtaining continuity of what is needed for repair and the tasks involved in construction.
The question as to whether, when and to what extent repair work or strengthening is necessary can only be answered by taking into account all boundary conditions relating to technical, time and financial aspects.
The objective must not always be to restore the original condition, indeed it can be quite sufficient both economically and technically to provide proper strengthening whilst, at the same time, downgrading the safe loading capacity. In this respect cost analyses can be of help. An estimate can also be obtained by studying the risks involved and giving consideration to the life of the structure as to the success of the repair measures proposed.

REFERENCES

/1/ FINSTERWALDER U.: Donaubrücke beim Gänstor in Ulm; Bauingenieur 1951

/2/ ZfP Bau-Symposium "Zerstörungsfreie Prüfung im Bauwesen" Oct. 1985, BAM-DGZfP Berlin

/3/ JUNGWIRTH D.; Bayer E., Grübl P.: Dauerhafte Betonwerke; Betonverlag Düsseldorf 1986

/4/ RANISCH E.H.: Zur Tragfähigkeit von Verklebungen zwischen Baustahl und Beton-geklebte Bewehrung; Dissertation TU Braunschweig 1982

/5/ SCHMITZ H.: Die Sanierung der Hochstraße im Heerdter Dreieck, Düsseldorf; Betontag Berlin 1979, DBV Schriftenreihe

/6/ FLESCH R., Kernbichler K., Grübl P.: Brückeninspektion mittels dynamischer Untersuchungen; VDI-Berichte 514, 1984

/7/ DIN 1076: Ingenieurbauwerke im Zuge von Straßen und Wegen, Überwachung und Prüfung