Civil Engineering

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TECHNICAL ENGLISH SUPPLEMENTARY READERS

SCOTT CIVIL ENGINEERING

Technical English Supplementary Readers

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Longman

This modern suspension bridge is a road bridge over the River Severn, England

Contents

1 Becoming a civil engineer

In the English-speaking countries, unlike Continental Europe, a professional engineer who wishes to be fully qualified, must join at least one engineering institution. All these institutions require candidates for admission to prove that they have some years of useful practical experience as an engineer. Each institution is a learned society not unlike a club except that the candidate's strict examination for membership is based mainly on his engineering knowledge, and all institutions publish engineering literature in their own subjects, usually in their monthly journal. Each has several grades of membership, from the highest, full Member, down through the usual grade, Associate-Member, to the grades of Student or Graduate for younger people up to about twenty-five or thirty years old.

In Britain it has always been possible for a boy on leaving school at fifteen to start work in the drawing* office of a civil engineer, whether contractor* or consultant*, and eventually after many years of study in his spare time, to become a qualified civil engineer. This is becoming less easy and it may soon become impossible. The recommended method of study for the ICE (Institution of Civil Engineers) examinations is now by full-time or sandwich* study for a degree or diploma*. Sandwich study is full-time work at a college interrupted by periods of full-time work with an employer.

Modern engineering requires more and more science, and to make use of its scientific theories, a civil engineer should study full-time for some years after leaving school. Therefore a university degree in civil engineering may soon become essential for membership of the ICE or any of the other civil engineering institutions (Institutions of Highway Engineers, Municipal Engineers, Public Health Engineers, Structural Engineers, Water Engineers, or the Permanent Way Institution, etc.).

To qualify for Associate-Membership of the ICE, a person must be at least twenty-six years old and working as a civil engineer. He must also pass certain examinations, satisfy the ICE that he has had several years of useful engineering experience under the supervision* of qualified civil engineers, both in the drawing office and on the site, and finally he must pass a mainly oral examination called the professional interview, before

*Words marked with this sign are explained in the Glossary, pages 91–108.

a group of qualified civil engineers. This is generally the only part of the examination from which candidates are never excused, whatever their civil engineering degree.

In general education, the minimum* requirements, before a man may be accepted even as a candidate for the ICE examinations are as follows: five passes in the General Certificate of Education, (a) at advanced level in physics, (b) at advanced level in either pure or applied mathematics, (c) at ordinary level in English, and (d) at ordinary level in two other subjects. Detailed information is issued free by the ICE on all matters including the parts of the examination a candidate need not take as well as on the number of years and the types of civil engineering experience which are accepted.

In Britain the thirteen main engineering institutions were formally joined for examination purposes in 1965 in the Council of Engineering Institutions in London. A similar arrangement was made a few years earlier in the United Engineering Center, 345 East 47th Street, New York, for the United States institutions. In Britain all professions now take the Part 1 examination set by the Council of Engineering Institutions. This includes the five subjects of engineering drawing, mathematics, applied mechanics, principles of electricity, heat light and sound.

2 Drawing office work

The main work in a drawing* office is done by draughtsmen* who use a pencil, T-square, set square and scale (Fig. 1) to make engineering sketches, designs, and finally details* or working drawings, from which the contractor can build the structure. The draughtsmen, among whom occasionally there are women, work under the civil engineering designer* in charge of their section of the work. Very often the chief of the drawing office, though he may be a highly qualified civil engineer, is called the chief draughtsman, though he may be called the chief designer and this is becoming commoner in civil engineering.

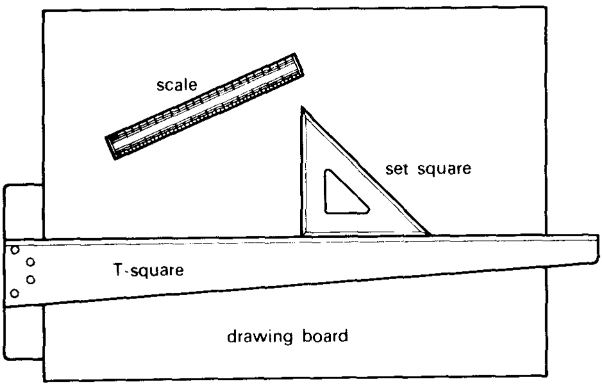


Fig. 1. Draughtsmen make drawings on a drawing board, using a pencil and a T-square, set square and scale

The drawings are made either on transparent* paper or on plastics film* (which is the most lasting) and prints are taken from the completed drawings. Until about 1950 the blueprint* was the commonest type of print, but this is now very unusual, and has been replaced by the dyeline* which has dark lines on a white background and is therefore easier to write on. The blueprint had white lines on a dark blue background.

The best drawings are of course made in black ink, but this is very much slower than pencil work, and may take up too much of the time of the skilled draughtsmen. Therefore tracers* are employed in some offices to trace in ink the drawings made in pencil by the draughtsmen or designers. Tracers are now usually women but some men work as tracers for their whole lives and they produce very fine work. Engineering drawings, however, are now less fine than fifty years ago, and therefore there is little demand for men tracers, who also need more pay than women.

In a consulting* engineer's office the designers discuss their work either directly with the client* or with a partner* who in turn discusses it with the client and obtains his approval for any change in policy. In a contractor's organization, partners do not exist because almost every contractor is a limited company. Partners exist in consulting engineers' offices because theoretically their responsibility is unlimited and in fact they have unlimited moral responsibility for obtaining the best structure possible for the client. The partners share this moral responsibility.

Many civil engineers in the course of their working life pass through all the stages mentioned in this article. They begin as juniors tracing drawings, they become draughtsmen after a short time, then they spend some time on a site* setting* out work and checking the contractor's monthly certificates*; they return to the office and take their examinations for the Institution of Civil Engineers, become designers, then senior designers and eventually partners.

An active man of twenty-six with a degree in civil engineering could be a designer at this age, a senior designer at thirty, and a partner at thirty-five in a go-ahead firm. Some civil engineers start their own businesses as consultants* but generally to do this some money is needed, or at least a bank's loan. Payment for work does not come in until some months after it is done and the loan is needed to enable the consultant to live and pay for work until he is paid. Generally one could assume that not less than £3,000 would be needed to set a man up in business after he has received promises for a year or two of work.

I must explain here what I mean by a go-ahead firm. In some consulting engineering firms, the partners are frightened that they know less than those who work for them, and they do not reward people who work hard and well. In a go-ahead firm the partners recognize that they very often do know less than those who have come more recently from their studies and they are anxious to reward men for good work. Such firms are go-ahead in more ways than one. They produce the best structures, and they attract the best men because they reward them well, and because the best men are naturally drawn to good work. In one go-ahead firm, men become associate partners (half partners) at the age of thirty, a truly astonishing age compared with the period of 1926–37 in Britain when fully qualified civil engineers of forty were happy to work as draughtsmen for a low wage.

3 Concrete technology

Concrete* has been used since Roman times and possibly earlier. The Romans even used lightweight* concrete for the roof of the Colosseum. With us lightweight concrete is a development mainly of the last twenty years. The cements the Romans used were different from ours though concrete can be made of any strong lime* or cement*.

But good, strong, long-lasting concrete did not become generally possible until cheap coal was available* and therefore cheap cement. Portland cement is made from the burning of finely-ground limestone or chalk mixed with clay*. This was first patented in 1824 but the cement was not in wide use until the beginning of the present century. It was only then that concrete technology* began. Concrete was originally used only because it was a strong, cheap replacement for masonry*. Very few limes ever reach the strength that cement can reach in a few days at ordinary temperatures (15° C).

Concrete technology is the making of plentiful good concrete cheaply. It includes the correct choice of the cement and the water, and the right treatment of the aggregates*. Those which are dug near by and therefore cheap, must be sized, washed free of clay or silt*, and recombined in the correct proportions so as to make a cheap concrete which is workable* at a low water/cement ratio*, thus easily compacted* to a high density* and therefore strong.

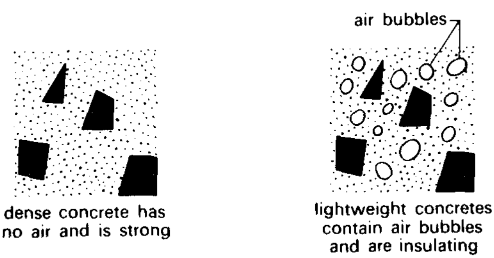


Fig. 2. Both concretes contain the matrix (sand and cement or lime). Dense concretes also contain larger stones, and lightweight concretes contain air bubbles

Abrams' law, perhaps the oldest law of concrete technology, states that the strength of a concrete varies inversely* with its water/cement ratio. This means that the sand content (particularly the fine sand which needs much water) must be reduced so far as possible. The fact that the sand 'drinks' large quantities of water can easily be established by mixing several batches* of x kg of cement with y kg of stone and the same amount of water but increasing amounts of sand. However if there is no sand the concrete will be so stiff that it will be unworkable therefore porous* and weak. The same will be true if the sand is too coarse. Therefore for each set of aggregates, the correct mix must be chosen after careful testing, and once found, this correct mix must not be changed without good reason. This applies particularly to the water content.

Any drinkable and many undrinkable waters can be used for making concrete, including most clear waters from the sea or rivers. It is important that clay should be kept out of the concrete. The cement if fresh can usually be chosen on the basis of the maker's certificates of tensile* or crushing tests, but these are always made with fresh cement. Where strength is important, and the cement at the site is old, it should be tested.

If no testing machines exist near by, a simple way of testing the strength of a concrete on a site is by casting a beam without reinforcement* and testing it until it breaks, the so-called modulus* of rupture test. The beam is about 10 cm square and 75 cm long. Its age of testing is noted and the beam is supported at two points at a measured distance apart and broken by applying to it a gradually increasing load, W kg, at a point halfway between the supports. If the supports are L cm apart, the bending* moment at the centre is $WL \times 0{\cdot}125$ kg-cm.

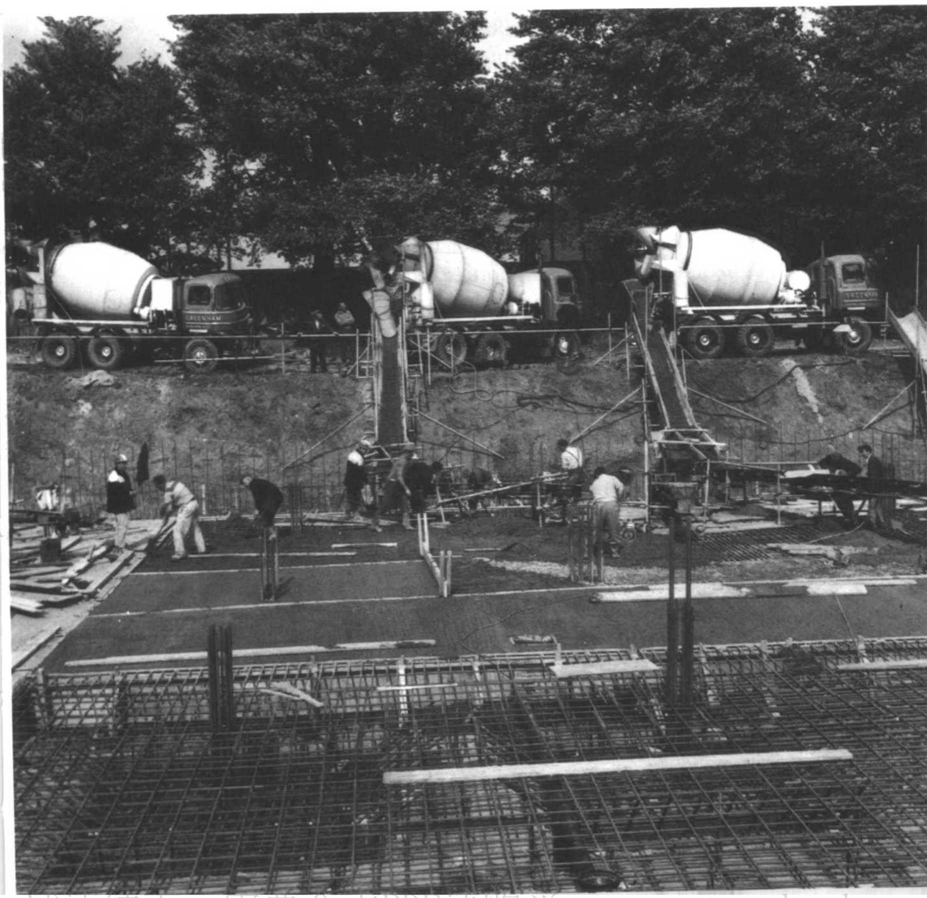
If the concrete is regarded as a material of uniform strength its maximum* stress* at failure can be obtained from this maximum bending* moment divided by the section modulus. A correction will have to be applied for the different bending moment (and lower maximum stress) if the beam does not break at the middle.

For a beam of square cross-section and side a cm, the section modulus will be $0{\cdot}167\ a^3\ \text{cm}^3$. In this instance $0{\cdot}167 \times 10^3 = 0{\cdot}167 \times 1000 = 167\ \text{cm}^3$ and the breaking stress will be $\frac{WL \times 0{\cdot}125}{167}\ \text{kg/cm}^2$.

This stress, causing breakage, will be a tension* since concretes are from 9 to 11 times as strong in compression* as in tension. This stress, the modulus of rupture, will be roughly double the direct tensile* breaking stress obtained in a tensile testing machine, so a very rough guess at the compressive strength can be made by multiplying the modulus of rupture by 4·5. The method can be used in combination with the strength results of machine-crushed cubes* or cylinders* or tensile test pieces but cannot otherwise be regarded as reliable. With these comparisons, however, it is suitable for comparing concretes on the same site made from the same aggregates and cement, with beams cast and tested in the same way.

The effort spent on careful grading*, mixing and compaction of concrete will be largely wasted if the concrete is badly cured. Curing means keeping the concrete thoroughly damp for some time, usually a week, until it has reached the desired strength. So long as concrete is kept wet it will continue to gain strength, though more slowly as it grows older.

Lorries delivering ready-mixed concrete



4 Concrete additives[1]

Admixtures or additives to concrete are materials which are added to it or to the cement so as to improve one or more of the properties* of the concrete. The main types are:

1. Accelerators* of set* or hardening*,
2. Retarders* of set or hardening,
3. Air-entraining* agents, including frothing or foaming* agents,
4. Gassing agents,
5. Pozzolanas*, blast-furnace slag* cement, pulverized* coal ash,
6. Inhibitors* of the chemical reaction between cement and aggregate, which might cause the aggregate to expand*
7. Agents for damp-proofing a concrete or reducing its permeability* to water.
8. Workability* agents, often called plasticizers*,
9. Grouting* agents and expanding cements.

Wherever possible, admixtures should be avoided, particularly those that are added on site. Small variations in the quantity added may greatly affect the concrete properties, and even the correct quantity may alter the concrete properties in an undesirable way. An accelerator can often be avoided by using a rapid-hardening* cement or a richer mix with ordinary cement, or for very rapid gain of strength, high-alumina* cement, though this is very much more expensive, in Britain about three times as costly as ordinary Portland* cement. But in twenty-four hours its strength is equal to that reached with ordinary Portland cement in thirty days.

A retarder may have to be used in warm weather when a large quantity of concrete has to be cast in one piece of formwork*, and it is important that the concrete cast early in the day does not set before the last concrete. This occurs with bridges when they are cast in place, and the formwork necessarily bends under the heavy load of the wet concrete. Some retarders permanently weaken the concrete and should not be used without good technical advice.

A somewhat similar effect, milder than that of retarders, is obtained with low-heat cements. These may be sold by the cement maker or mixed by

[1]With acknowledgements to L. C. Urquhart, *Civil Engineering Handbook*, and to the American Concrete Institute.

the civil engineering contractor. They give out less heat on setting and hardening, partly because they harden more slowly, and they are used in large casts such as gravity* dams, where the concrete may take years to cool down to the temperature of the surrounding air. In countries like Britain or France, where pulverized coal is burnt in the power stations, the ash, which is very fine, has been mixed with cement to reduce its production of heat and its cost without reducing its long-term strength. Up to about 20 per cent ash by weight of the cement has been successfully used, with considerable savings in cement costs.

In countries where air-entraining cement can be bought from the cement maker, no air-entraining agent needs to be mixed in. When air-entraining agents draw into the wet cement and concrete some 3–8 per cent of air in the form of very small bubbles, they plasticize the concrete, making it more easily workable and therefore enable the water/cement ratio to be reduced. They reduce the strength of the concrete slightly but so little that in the United States their use is now standard practice in road-building where heavy frosts occur. They greatly improve the frost resistance of the concrete.

If an air-entraining cement is heavily whisked*, as much as 60 per cent of air may be drawn into the concrete, but the air-entraining agent is then regarded as a foaming agent or frothing agent. Normally to produce a thermally* insulating*, not a structural* concrete, some 30–60 per cent of air is drawn in. Air-entraining agents were first used around 1940 in the United States for roadbuilding, but because they plasticize the concrete they have been sold as workability agents, or plasticizers.

Gassing agents are those which produce a foam in a cement or mortar mix without whisking but by a chemical action. The main gassing agent in use is the fine aluminium* powder used in factories making aerated* concrete. It is highly unlikely that any of these factories will be operated by a civil engineer, so we need discuss them no further.

Pozzolana is a volcanic ash found near the Italian town of Puzzuoli (other spellings exist), which is a natural cement. The name has been given to all natural mineral cements, as well as to the ash from coal or the slag* from blast furnaces, both of which may become cements when ground and mixed with water. Pozzolanas of either the industrial or the mineral type are important to civil engineers because they have been added to ordinary Portland cement in proportions up to about 20 per cent without loss of strength in the cement and with great savings in cement cost. Their main interest is in large dams*, where they may reduce the heat given out by the cement during hardening. Some pozzolanas have been known to prevent the action between cement and certain aggregates which causes the aggregate to expand, and weaken or burst the concrete.

The best way of waterproofing a concrete is to reduce its permeability* by careful mix* design and manufacture of the concrete, with correct placing and tight compaction in strong formwork* at a low water/cement ratio. A small amount of plasticizer may help to reduce the water/cement ratio. Even an air-entraining agent can be used because the minute pores are discontinuous. Slow, careful curing of the concrete improves the hydration* of the cement, which helps to block the capillary* passages through the concrete mass. An asphalt* or other waterproof skin is often effective and cheap but of course is not a concrete additive. It should perhaps be mentioned that the term 'integral waterproofing' means the waterproofing of concrete by any method concerned with the quality of the concrete but not by a waterproof skin.

Workability agents, water-reducing agents and plasticizers are three names for the same thing, mentioned under air-entraining agents. Their use can sometimes be avoided by adding more cement or fine sand, or even water, but of course only with great care.

5 Prestressed concrete

The rapid growth from 1945 onwards in the prestressing* of concrete shows that there was a real need for this high-quality structural material. The quality must be high because the worst conditions of loading normally occur at the beginning of the life of the member, at the transfer* of stress from the steel to the concrete. Failure is therefore more likely then than later, when the concrete has become stronger and the stress in the steel has decreased because of creep* in the steel and the concrete, and shrinkage* of the concrete. Faulty members are therefore observed and thrown out early, before they enter the structure, or at least before it becomes inconvenient and expensive to remove them.

Prestressed concrete bridge over a motorway in England

The main advantages of prestressed concrete in comparison with reinforced* concrete are:

(a) The whole concrete cross-section* resists load. In reinforced concrete about half the section, the cracked area below the neutral* axis, does no useful work. Working deflections* are smaller (Fig. 3).
(b) High working stresses are possible. In reinforced concrete they are not usually possible because they result in severe cracking which is always ugly and may be dangerous if it causes rusting of the steel.
(c) Cracking is almost completely avoided in prestressed concrete.

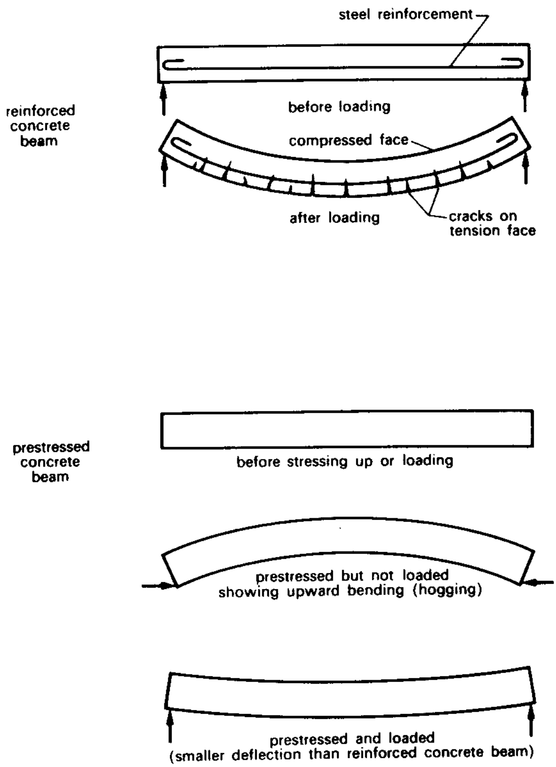


Fig. 3. Prestressed concrete and reinforced concrete

The main disadvantage of prestressed concrete is that much more care is needed to make it than reinforced concrete and it is therefore more expensive, but because it is of higher quality less of it needs to be used. It can therefore happen that a solution of a structural problem may be cheaper in prestressed concrete than in reinforced concrete, and it does often happen that a solution is possible with prestressing but impossible without it.

Prestressing of the concrete means that it is placed under compression before it carries any working load. This means that the section can be designed so that it takes no tension or very little under the full design load. It therefore has theoretically no cracks and in practice very few. The prestress is usually applied by tensioning the steel before the concrete in which it is embedded has hardened. After the concrete has hardened enough to take the stress from the steel, some of the stress is transferred from the steel to the concrete. In a bridge with abutments* able to resist thrust*, the prestress can be applied without steel in the concrete. It is applied by jacks* forcing the bridge inwards from the abutments. This method has the advantage that the jacking force, or prestress, can be varied during the life of the structure as required.

In the ten years from 1950 to 1960 prestressed concrete ceased to be an experimental material and engineers won confidence in its use. With this confidence came an increase in the use of precast* prestressed concrete particularly for long-span floors or the decks* of motorways*. Wherever the quantity to be made was large enough, for example in a motorway bridge 500 m long, provided that most of the spans* could be made the same and not much longer than 18 m, it became economical* to use factory-precast prestressed beams, at least in industrial areas near a precasting factory. Most of these beams are heat-cured* so as to free the forms quickly for re-use.

In this period also, in the United States, precast prestressed roof beams and floor beams* were used in many school buildings, occasionally 32 m long or more. Such long beams over a single span could not possibly be successful in reinforced concrete unless they were cast on site* because they would have to be much deeper and much heavier than prestressed concrete beams. They would certainly be less pleasing to the eye and often more expensive than the prestressed concrete beams. These school buildings have a strong, simple architectural appeal and will be a pleasure to look at for many years.

The most important parts of a precast prestressed concrete beam are the tendons* and the concrete. The tendons, as the name implies, are the cables*, rods or wires of steel which are under tension in the concrete.