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Main Theme D

New Frontiers in Structural Engineering

Les nouvelles frontières du génie des structures

Aufbruch zu neuen Grenzen im konstruktiven Ingenieurbau

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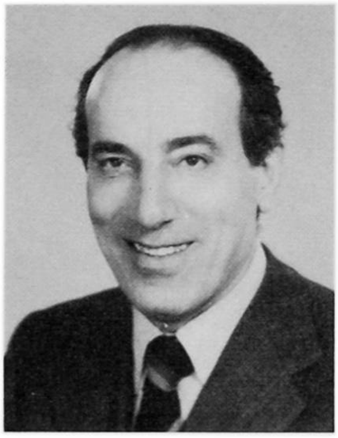


Leo Finzi, born 1924, has been a full professor of Theory of Structures since 1958. Author of papers on elastoplasticity, stability and dynamic analysis of structures, he has been and is the designer of outstanding steel and concrete structures.

SUMMARY
This general report is intended to make engineers aware of what is really inventive today in structural engineering (new types of structures, new ideas and methods in design, fabrication and erection) and what could be expected in the „nineties" i.e. in the near future.

RESUME
Ce rapport devrait permettre aux ingénieurs de prendre conscience de ce qui est vraiment inventif dans le génie des structures: nouveaux types de structures, nouvelles idées et nouvelles méthodes de projet, de fabrication et de construction. Il présente les tendances possible pour les années „quatre vingt-dix".

ZUSAMMENFASSUNG
Der Bericht hat zum Ziel, den Ingenieuren bewusst zu machen, was im Bereich des konstruktiven Ingenieurbaus heute wirklich neuartig ist (neue Arten von Tragwerken, neue Ideen und neue Methoden des Entwurfs, der Fabrikation und der Konstruktion) und was für die 90er Jahre — für nächste Zukunft also — erwartet werden könnte.

1. INTRODUCTION

In order to try to foresee what tomorrow's structural engineering may be like, it would probably be best to analyse the new ideas that already exist today, the new technologies that are about to emerge from the experimental stage. It would also be necessary to consider what might be the requirements of our society in the near future, and so what might be the demands made on tomorrow's engineers. To do this does not imply that we have to become visionaries gazing into the next century, but we can discuss what may lie in store for structural engineering in the next decade.

Structural engineering evolves and progresses together with the evolution, progress and refinement of:

- materials
- structural components and fasteners
- structural shapes
- physical, mathematical and numerical models
- fabrication techniques
- erection techniques

One of the purposes of this introductory report is to draw the attention of possible contributors to this session of the 12th IABSE Congress to possible or desirable innovations in the fields just mentioned, in the hope that they will then give us the benefit of their ideas and proposals.

In other words, our intention here is to encourage architects, engineers and, in general, those involved in this field, to present papers on whatever there is that is really new and inventive (new types of structures, new structural concepts, new fabrication and erection techniques), and on whatever might reasonably be expected in the near future. Even ideas which today seem utopian may in fact soon become a matter of common practice.

2. MATERIALS

Materials now exist which have already made great technological advances, such as structural steel and concrete. Others, such as plastics and aluminium alloys, still have not overcome all the obstacles facing them in terms of their structural application - obstacles of some importance from the point of view both of their reactions to the environment (temperature, weather conditions etc.) and of their production costs. Even for the well-tried traditional materials there are still good hopes of progress.

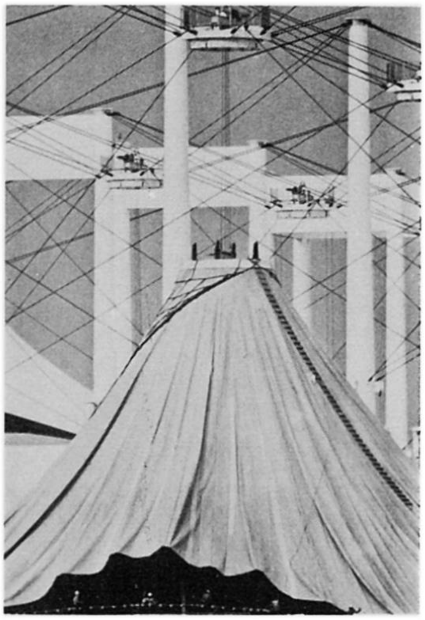


Fig. 1 Jiddah air terminal under erection

Structural engineers, for example, still reasonably hope for improvements in steel to deal with problems of elastoplastic instability. Of course, it would be best if this could be done by increasing the values of Young's modulus through metallurgic operations on the orientation of the crystal lattice, but if not, at least by developing manufacturing processes to reduce to a minimum the residual stresses, which panalise metal components in general and columns in particular |1|.

Would it not also be reasonable to hope that present studies on various types of fibre reinforced concrete may eventually give us a material able to cope not only with compression, but also with tension and shear?

Increasing energy costs do not leave much room for hope in the increased use of aluminium alloys for structural engineering, at least in the near future. The situation may be more hopeful in the field of plastic materials, whether used for wires or cables, profiles or even for two-dimensional sheets (Fig. 1).

It is well known that for large span structures a decisive parameter is the critical length L_{cr} of the material involved which is the ratio between the yield strength F_y and the specific weight γ (i.e. $L_{cr} = F_y/\gamma$).

A characteristic of plastic materials is that their specific weight is of the order of one. Since the yield strength is not much less than for standard steel, these materials seem to have advantages where the dead weight of structures plays a dominant part.

But the dead weight may also be decisive for large span reinforced concrete structures. Here, great progress may be achieved if really lightweight concretes can be obtained (i.e. with less than half the specific weight of normal concrete) without too much reduction in the compressive and tensile strength and the elastic modulus.

There may be many ways to obtain this desirable result: the use of light aggregates with expanded clay, the use of concretes incorporating expanded polystyren balls, the air-entrainment of the concrete. Each of these different possibilities involves differences in mechanical behaviour, which should receive very careful attention, since the well known characteristics of ordinary concrete can certainly not be extrapolated to these newer types.

Masonry of bricks and mortar was all very well when man's principal tools were his hands, but now it must give way to new mixtures which offer the same possibilities for insulation, but which can be dealt with by machines.

One result is much greater freedom of choice for size and shape: panels, folded beams, entire box units can be cast to obtain monolithic elements that may be even very large and have the desired characteristics not only of strength but also of insulation.

When discussing construction materials, the foundation soil must not be forgotten, since it is one of the essential components. The type of soil is an essential factor, decisive for the choice of foundation systems in general, above all, of course, for underground work such as tunnels or wells. Here, the way that the soil is treated to render it as suitable as possible for particular requirements is really fundamental.

Foamed cements, acrylic fibers, epoxy resins already make it possible to transform otherwise totally unsuitable silts into something even better than sand or gravel.

3. STRUCTURAL COMPONENTS AND FASTENERS

The sinking of suitably shaped reinforcing bars into concrete castings and the use of tendons for prestressing led to completely new structural components.

Another breakthrough was the design of large steel beams made up of plates suitably strengthened by longitudinal and transversal stiffeners. Even wood, perhaps the oldest of all structural materials, has been improved by lamination to remove its anisotropic defects.

What may be the next developments for the immediate future?

The growing use of meshes and textile materials perhaps even together, seems very promising, particularly in terms of high performance versus low dead weight (Fig. 2) |2|. Glassfibre - reinforced polyester resins have also by now established a place for themselves in the construction of light and efficient

Fig. 2 U.S.A. Pavillion air supported roof at Osaka Expo 70

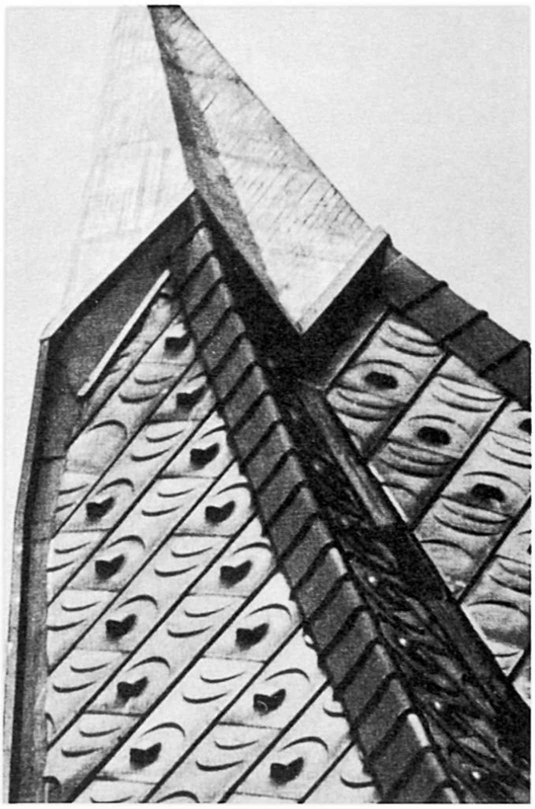


Fig. 3 Fiberglass reinforced polyester panels

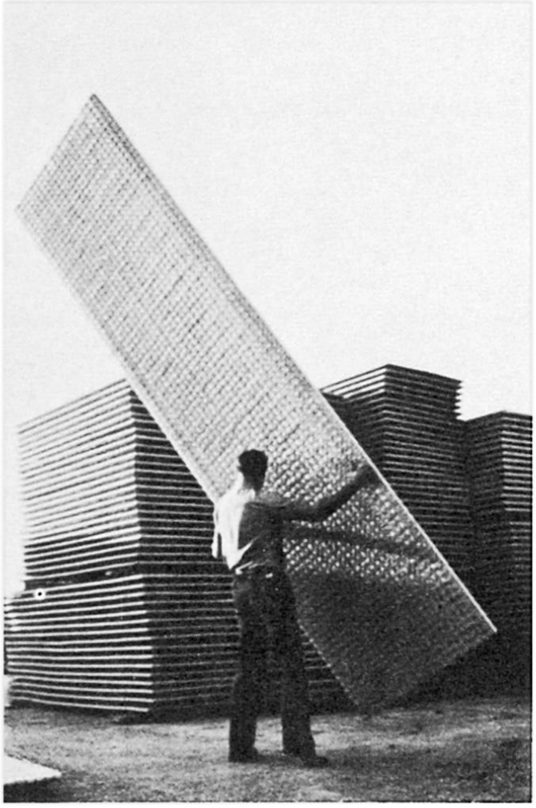


Fig. 4 Extralight steel reinforced panels before cement gun spray

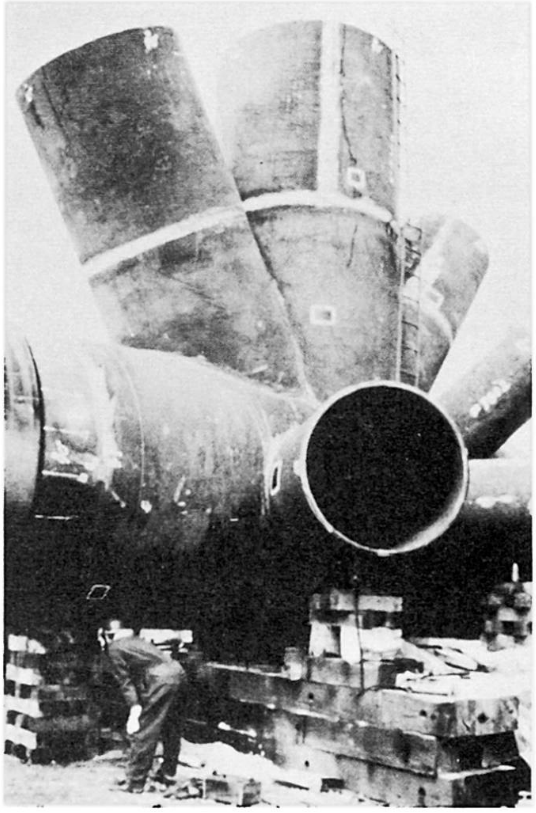


Fig. 5 Jumbo offshore truss welded connection

structural components (Fig. 3) |3|.

For smaller spans there are now sandwich constructions which incorporate within the insulating core a light steel space frame to connect the external concrete layers. They have proved to be particularly suitable for low cost housing (Fig. 4).

The rapid development in the use of macrostructures must also be considered, not only for large offshore constructions but even for residential purposes. This has led to notable progress in the construction of components of exceptional length and width. Tubular constructions seem to offer the greatest advantages here, to deal with problems of statics and the technological difficulties involved. However, the dimensions of these sections are so great that it seems better to think of them in two-dimensional terms, rather than as traditional one-dimensional elements (Fig. 5).

The combination of steel with concrete has had great success in structural engineering in various forms, from the traditional reinforced and prestressed concretes to composite steel-concrete structures (steel beams with reinforced concrete slabs, corrugated sheeting combined with concrete filling). Might it not be possible to combine other materials equally successfully, such as alluminium alloys, wood, nylon and so on?

Perhaps even more impelling is the need for innovation in the field of connections.

Steel member connections and the joints of corrugated rebars in reinforced concrete must be capable of simplification. I am, of course, referring to connections made on site, since fasteners manufactured in shop or prefabrication centres can already profit from automatic welding processes and rebar connections of the Bar Grip, Lenton or Cadweld type that have already been highly simplified and rationalised.

Will glued connections have a prosperous future?

The example of the aeronautics industry might lead to an easy optimism, but it would be well to remember that an open building site is not quite the same thing as a Boeing aircraft plant.

Nowadays, the impulse towards the highest possible degree of simplification for in-situ joints has led to favouring hinged type buildings almost everywhere, whether in steel or reinforced concrete. However, it may not always be the right answer, because not only does it imply giving up the economic advantages deriving from continuity between structural members, but it also leads to structures that are not ductile enough to resist earthquakes, and that may be subject to progressive collapse as a chain reaction to local damage.

Will it be possible to make subsequent modifications to a joint, when the structure has already been erected, to ensure full continuity between the members meeting there? Work of this kind has already been done on some offshore constructions |4|.

4. STRUCTURAL SHAPES

The last decades have been so richly stocked with innovations in the realm of structural shapes that it might seem that there is little more to be said. Shells, folded plates, hanging roofs, space trusses, box structures have all been widely used for constructions of considerable importance. The designs of high-rise buildings have also changed, particularly in the bracing systems, and can now reach heights of over 400 m and eliminate the intermediate columns at each floor |5|. As to bridges, the introduction of box girders with orthotropic plates, the use of straight stays for spans of hundreds of metres, and the capacity to control aeroelastic instability over exceptionally long spans through suitable expedients have permitted the design of some constructions of great beauty and originality.

It seems to me, however, that stimulating new problems are about to be posed. Look at a nuclear power plant, normally close to the sea or a large river, rising on ground that may be none too reliable, enclosed within massive walls rather like some medieval castle. Then think how much more interesting it might be to construct floating power plants anchored offshore or even under the sea. The offshore drilling platforms (Fig. 6) already allow for immerse containers located at as much as 500 m in depth. As in the case of Mahomet and the mountain, if the water will not come to the power station, we can take the station to the water.

As to more normal buildings, it is true that we have learnt to go up to over 100 floors, but why not abandon the traditional idea of isolated blocks and connect them together in macrostructures that will join up working and residential requirements with the road system of the city.

Cable and inflatable structures, with many excellent examples already in existence, lead one to consider coverings for large areas. It is thought, for example, that a translucent plastic dome 2 cm thick set up over a diameter of 2 km (Fig. 7) and with a maximum height of 400 m (i.e. covering an entire city center) could tollerate an internal overpressure of 1500 Nm^{-2}, quite enough to compensate for any normal actions (such as snow and wind) due to weather conditions |6|.

The surface of the earth has large deserts burnt by the sun all through the year, where regulating the climate in inhabited areas is of fundamental importance. The area available is vast, with inexhaustible solar energy on the spot. Structural engineering can help to solve the problem, and Schleich's ideas (Figs. 8 and 9) |7| on the subject are the result of his brilliant work on cable-net cooling towers |8|.

Man's needs are changing more and more rapidly, and to deal with this situation of great mutability, structures are required with the smallest number of constraints to spatial distribution, both for industrial and residential buildings. All of this tends to lead towards long spans. Large public works, too, show the same trend, road systems with the relative bridges, tunnels etc.,

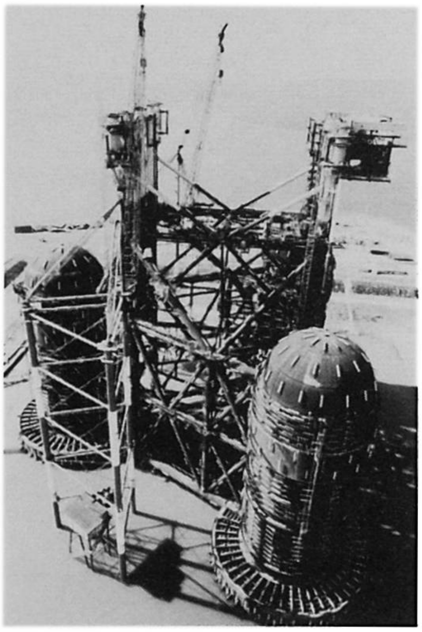


Fig. 6 A tall North-sea platform

Fig. 7 A feasible plexiglass dome over midtown Manhattan

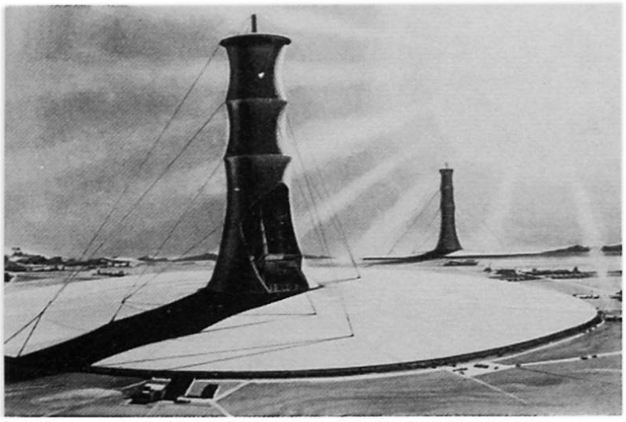


Fig. 8 Recovering solar energy

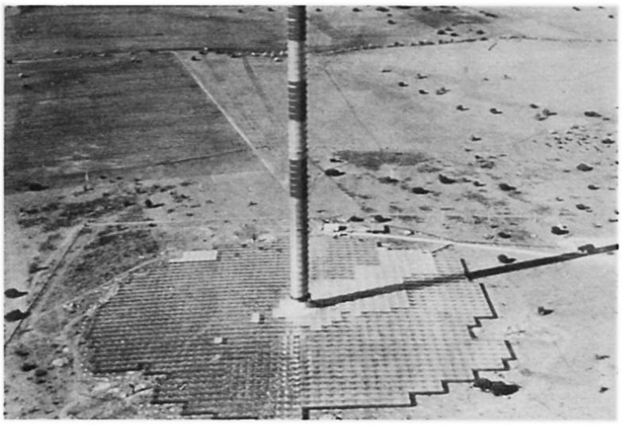


Fig. 9 Schleich's pilot power plant

airport installations, tanks for liquids and gas. But perhaps bridge construction, whether above or below the surface, offers the greatest challenge. In Europe alone of pressing importance, and calling for solution within this century, are the problems of crossing the Straits of Gibraltar, Messina (Fig. 10) |9| and Dover, while Japan has problems of at least equal importance for road and rail connections between its islands. But why should we be limited to this planet?

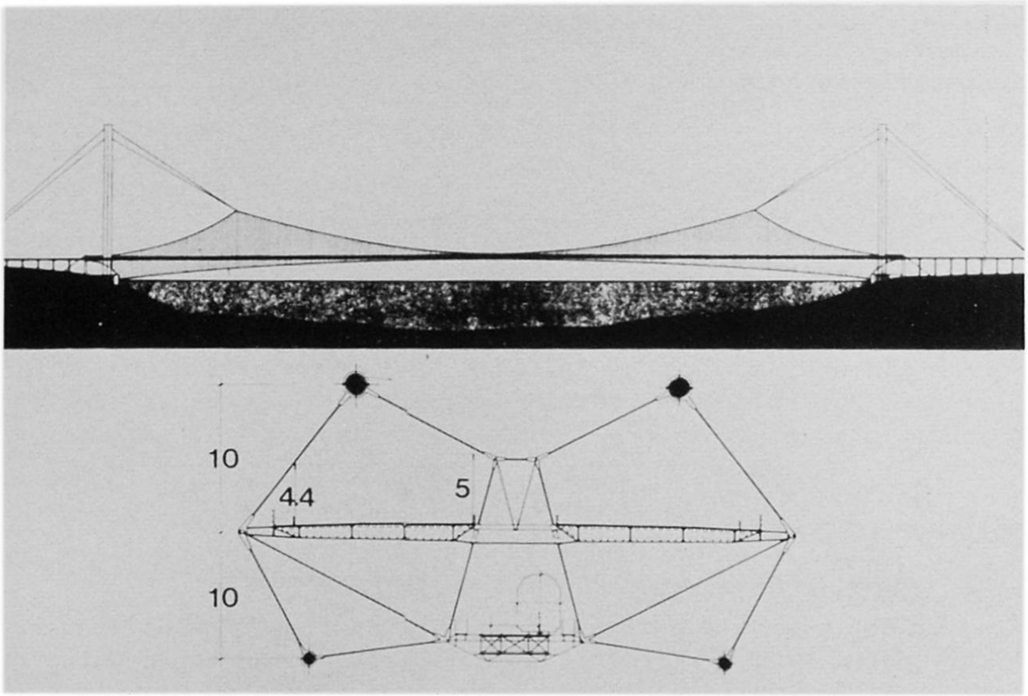
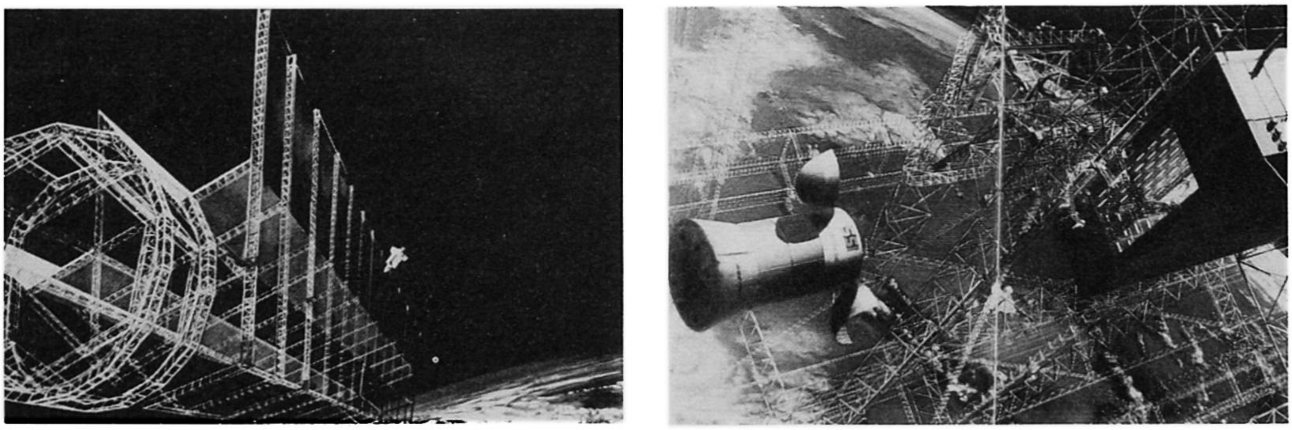


Fig. 10 "Hanging" bridge for the Messina Strait crossing

Theodor von Karman, when addressing a conference on scientific models at Venice in 1954, spoke about landing on the moon and planetary exploration by means of rocket propelled vehicles. Many in the audience doubted if this was suitable for a rigorously scientific conference. But less than thirty years later we already have to face the problem of building large artificial satellites to orbit around the earth (Figs. 11 and 12), access and construction being facilitated by vehicles like the Shuttle |10|.

This will really be a fresh field for the structural engineer, accustomed as he is to struggling with the forces of gravity, but perhaps less prepared to deal with the problems of temperature variation that here will assume a role of much greater importance.



Figs. 11 and 12 Space platforms

5. PHYSICAL, MATHEMATICAL AND NUMERICAL MODELS

New materials, new structures, new environmental situations will raise new design and checking problems for the structural engineer of the 1990's. Among the new tools that we already have, but that will be even more formidable in the near future, are the computers, rapidly becoming more available to small groups or even individuals, easier to handle and, of great importance for the structural engineer, suitable for displaying the input and output.

The same sort of thing can also be said for optimisation techniques, which are becoming more and more refined - another area of fundamental importance for improvements in design.

The physical model, on the other hand, referring to an entire structure - the sort of model that men like Esquillan, Nervi and Torroja used to try out their brilliant ideas - seems to have a less happy future. But the trend towards industrialized building tends to stress the systematic use of laboratory tests on constructional details, such as fasteners and structural nodes. All modern universities have suitable test-beds for trying out these structural elements in realistic conditions, applying pre-fixed loading histories.

6. FABRICATION TECHNIQUES

The modern building is more becoming an industrial product.

The building trade itself, one of the most backward in terms of industrialisation, is rapidly trying to make up for lost time. So structural engineering has to find solutions that are optimal also in the sense that they are suitable for mass production. The key-words today are unification and standardisation, i.e. the aim of research is to find satisfactory final solutions made up of a limited number of components that are suitable for mass production. This system, which we all used as children when we played with our "Meccano" sets, has already registered a number of notable successes. The Buckminster Fuller domes (Fig. 13) and the Mero space trusses (Fig. 14) are typical examples. But these are perhaps extreme cases. However, even when such a high degree of unification is not possible, the trend is anyway to increase as much as possible the quantity of factory work on the components with a consequent reduction in the amount to be done on site. When even this is not possible, and wherever the size of the construction permits, an actual workshop is first built on the site for the pre-assembly of the components to be erected. As a result, the necessary hoisting equipment is already impressive, and will be even more so in the future. Shipyards and the oil industry are already employing cranes with carrying capacities of 10 MN.

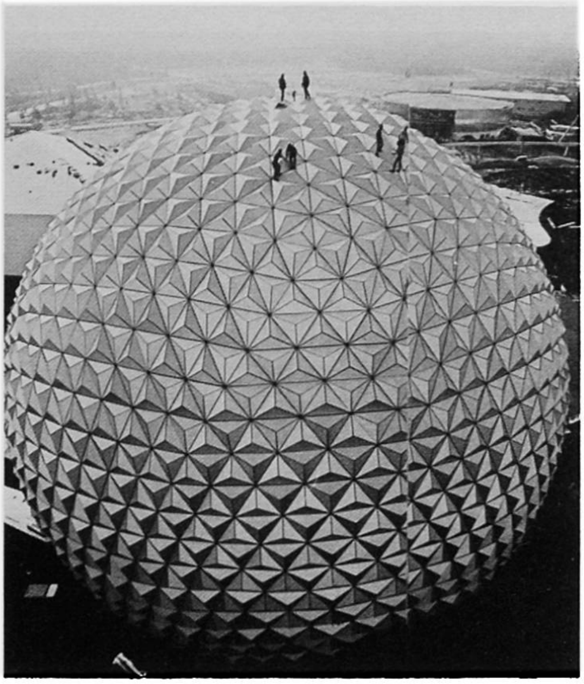


Fig. 13 Fuller type dome in Florida U.S.A.

Fig. 14 Space truss of the Mero system

Another aspect of this process is that not only the structures themselves are pre-assembled, but they often come fully equipped with all the necessary installations and finishings, so that once erected all that is required is a little fastening and sealing, and the building is ready for use.

7. ON SITE ERECTION TECHNIQUES

There have been many notable advances in the field of erection techniques, so that the right choice is a matter of considerable importance. When bidding for a bridge-building contract, for example, the erection technique may well be decisive. Nowadays, this generally means prefabricating the beams on the site and then sliding them forwards until they jut out, or else one proceeds by sections, cantilevered symmetrically over the piers (Fig. 15). The use of bentonite for diaphragm walls or large diameter piles has revolutionized the methods, times and

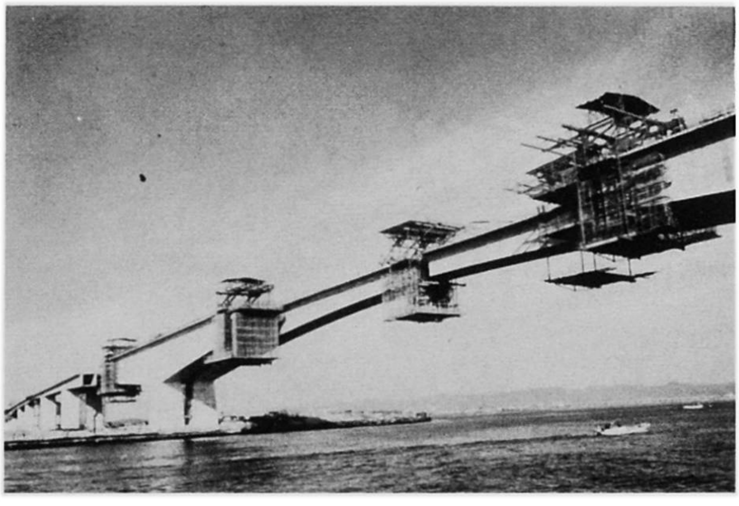


Fig. 15 Cantilevering of a prestressed concrete bridge

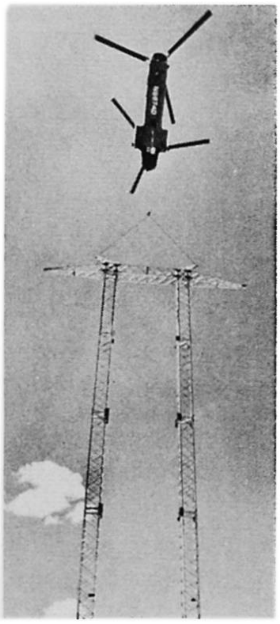


Fig. 16 Erecting a transmission tower by helicopter

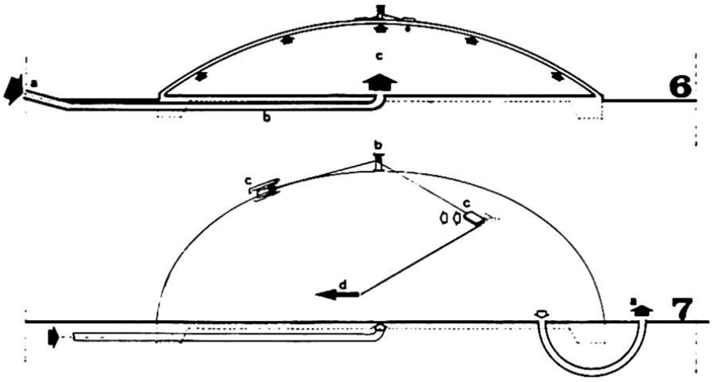


Fig. 17 Parashell inflatable formwork system

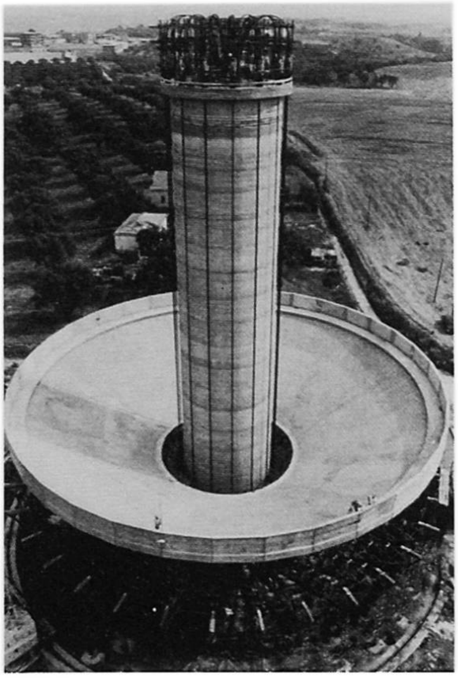


Fig. 18 Lifting an elevated reinforced concrete water tank

costs of foundations work. The use of vertical sliding or climbing formwork and of horizontal forms supported by joists as well as reinforced concrete "predalles" has eliminated or any-way greatly reduced the tubular scaffolding in building sites.

Derricks for erecting latticed towers have sometimes even been replaced by helicopters (Fig. 16).

The proper use of retarders makes it possible to cast a layer of reinforced concrete on a flat rubber sheet. Air is then blown under the sheet to inflate it, thus creating a dome of considerable size without the use of formwork (Fig. 17).

Finally, one might mention the hydraulic jacks that hoist entire packs of floor slabs or elevated tanks from their assembly at ground level to their required height (Fig. 18).

8. CONCLUSIONS

So far as structural engineering is concerned, the "new frontier" means that there are new goals to be reached. These goals, of course, will be the demands of an evolving society.

Some of them are already fairly clear.

The population explosion, especially in economically developing areas, and migration towards crowded conurbations, raise the basic problem of massive housing programs at low cost. There is no easy solution, and structural engineering has been playing its part for some time now. No great successes have so far been registered, but this has not been for lack of trying. Solutions must be found in the near future, and the structural engineer will be called on to give his contribution.

Housing, however, satisfies only one of man's basic needs. Social life also demands space both for work and for relaxation, and this implies areas to be covered and organised and inter-connected with residential districts.

There is also the demand for energy in all its available forms: heat, water-power, geothermics, nuclear, wind and solar energy.

New horizons are opening here too for the structural engineer. In fact, if one thinks of the offshore platforms, it may well be that the structural element is even more important here than for housing.

The ever-increasing mobility of modern man also raises fundamentally structural problems. New transport systems mean new bridges, viaducts, tunnels.

All these trends can easily be seen in present day society. But if we want to prepare for the future, it is not enough just to extrapolate from the present. We must bear in mind possible developments of situations that are now only in embryo but that may evolve as a reaction to the unfavourable consequences of present policies. From this point of view it seems quite probable that men will have to learn to live and work in areas that today would be considered hostile - deserts and other areas subject to extreme climatic conditions. It already seems probable that the sixth continent (the oceans) will be increasingly subject to the works of man, both above and below the surface. Man in space is already a scientific and technical fact, but not yet a social problem. The exploitation of the oceans, however, and of their immense energy resources, is already a question for the immediate future, and some interesting work has already been done (Fig. 19).

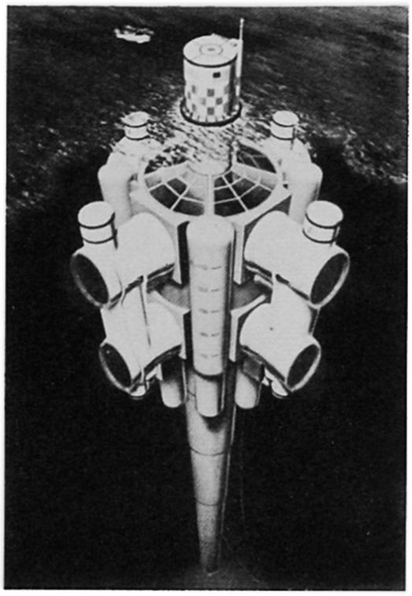


Fig. 19 T.Y. Lin Ocean thermal energy conversion (OTEC)

As to structural engineering, we can see the many problems that have yet to be solved, but really new ideas, by their very nature, have still to come into the open. They will come from architects, engineers, builders and even, why not, from outsiders. But it is not easy to foresee what they will be.

This introductory report is directed to those who have these new ideas, deriving from solid scientific and technical bases, to encourage them to bring out their new concepts, new methods, new techniques, to help structural engineering reach its new fontier.

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