Zeitschrift: IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht

Band: 10 (1976)

Artikel: Model contribution to the design and safety control of large structures

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DOI: https://doi.org/10.5169/seals-10502

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Model Contribution to the Design and Safety Control of Large Structures

Contribution des modèles physiques au projet et au contrôle de la sécurité des grandes structures

Beitrag des Modellversuchs an den Entwurf und die Sicherheitskontrolle von grossen Bauwerken

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1. SAFETY ANALYSIS (ON A MODEL) AND OPTIMIZATION

The model study can be conducted as:

I) a modern method of stress analysis;

II) a tool evaluating the critical, or ultimate load.

In case I) the model, usually associated with an electronic processing device, operates as a clever stress calculating machine, and the results obtained can be compared with those provided by using computers of great capacity.

In case II) the ultimate carrying capacity of the structure can be evaluated and the investigation can also concern various types of loads. In this case, the study is completed by determining the "minimum" overall factor of safety of the structure.

2. ELASTIC MODELS

Widely used in stress analysis, they can be subdivided in two groups:

- the first group concerns models of plane structures; the importance of these methods has decreased owing to the ever greater use of the "finite element method".
- The second group generally deals with three-dimensional structures.

In statical tests, electrical deflectometers and extensometers, usually applied to the surface of the model in various directions, measure displacements and strains respectively (fig. 1). The model material may differ from the prototype material, providing it obeys Hooke' s law and its Poisson' s ratio differs slightly.

The model operates as an "analogical computer", and the final results obtained, easily collected by means of a computer, can be compared with the theoretical ones.

In dynamic tests electromagnetic exciters are applied and piezoelectric accelerometers are used as measuring instruments. The strains are still furnished by strain gauges connected to regular amplifying and recording electrical equipment.

Auxiliary masses are conveniently distributed throughout the model to comply with dynamic similitude (fig. 2).

3. STRUCTURAL MODELS

These serve for testing beyond the elastic range and are usually made of the same materials as the prototype. This is possible for steel and reinforced or prestressed concrete structures when suitable scale (1:5 - 1:20) models are used (fig. 3). But for large structures, such as dams, reasons of economy make it necessary to adopt small scale models (1:50 - 1:150), and then model materials whose mechanical properties are "reduced" with respect to those of concrete, in accordance with similitude.

For these models, ISMES has long been using microconcrete simulating the properties of concrete up to failure, and adopting the technique of "wet" models (with waterproof coating) that are pratically without internal stresses.

The tests are conducted in two successive stages. In the first stage, "at working load", the model strains are investigated, under loadings corresponding to the actual working loads.

The second stage concerns "ultimate load tests", and it is made by gradually increasing the applied loads. The ratio between the maximum load actually supported before the collapse and the normal working one is assumed as the overall "factor of safety" of the structure with respect to that "type" of load.

Special mention should be made of earthquake simulation in dynamic tests. ISMES has long had the necessary equipment, which also fully meets all the requirements (fig. 4).

4. GEOMECHANICAL MODELS

These are a speciality of ISMES and investigate structures resting on foundation whose equilibrum or settlement conditions may affect the safety of the structures themselves (large bridges, dams, power or highway tunnels, etc).

5. ON STRUCTURAL SAFETY IN THE DESIGN STAGE

Models are of great importance during the design of large structures, especially if they are structurally complicated and highly hyperstatic.

Of the many cases studied at ISMES, mention is made for:

- the tests carried out on elastic models of large viaducts such as, for instance, the Polcevera and Maracaibo bridge type; or of tall buildings, such as the reinforced concrete building in Montreal, Canada (fig. 5);
- the analysis, by means of structural models carried to failure, of new types of structures. Of the unusual cases mention will be made of the models of prestressed concrete vessels for nuclear reactors and of those of St. Mary's Cathedral in San Francisco, California (fig. 6);

the geomechanical models used to analyze several concrete dams modeled with their foundation, e.g. the Kurobe IV dam (in Japan) and to investigate the stability of power or highway tunnels.

7. ON THE SAFETY FACTOR OF EXISTING STRUCTURES

Models can be of great value when the stability and safety degree of existing structures are to be checked. Particularly when large structures are to be verified, especially when actual statical or dynamic (seismic) conditions were not entirely foreseen in the design stage.

Among the models which yelded highly significant results for evaluating the safety factors brief mention will be made of:

- the failure tests on 1:4 scale models (fig. 7) to investigate the safety of the main columns carrying the "Duomo", i.e. the Cathedral in Milan. The two different materials used (Candoglia marble and Serizzo granite) and the geometry of the individual blocks were identical with those of the prototype.
  The stress conditions in the masonery dome bearing the main spire of the Cathedral were also examined on a large 1:15 scale elastic model (fig. 8).
- Sub-horizontal microcracks were found on the upstream of a large Italian arch-gravity dam. The influence of these cracks on the safety was investigated on a large structural model in which the microcraks had faithfully been reproduced.
- The effect of the foundation rock anysotropy horizontally stratified on a gravity dam in Spain was studied on geomechanical models (fig. 9).

REFERENCES: For more details on testing and results, please ask for Technical Bulletins of ISMES - P.O. Box 208, 24100 Bergamo (Italy).

SUMMARY

The present-day contribution of physical models to the design and safety control of large structures are presented; such investigations are systematically carried out at the author's laboratories.

RESUME

La contribution actuelle des modèles physiques au projet et au contrôle de la sécurité des grandes structures est présentée; de telles recherches sont effectuées de façon systématique aux laboratoires de l'auteur.

ZUSAMMENFASSUNG

Der heutige Beitrag des Modellversuchs an den Entwurf und an die Sicherheitskontrolle von grösseren Tragwerken wird dargestellt. Solche Untersuchungen werden systematisch in der Versuchsanstalt des Autors durchgeführt.

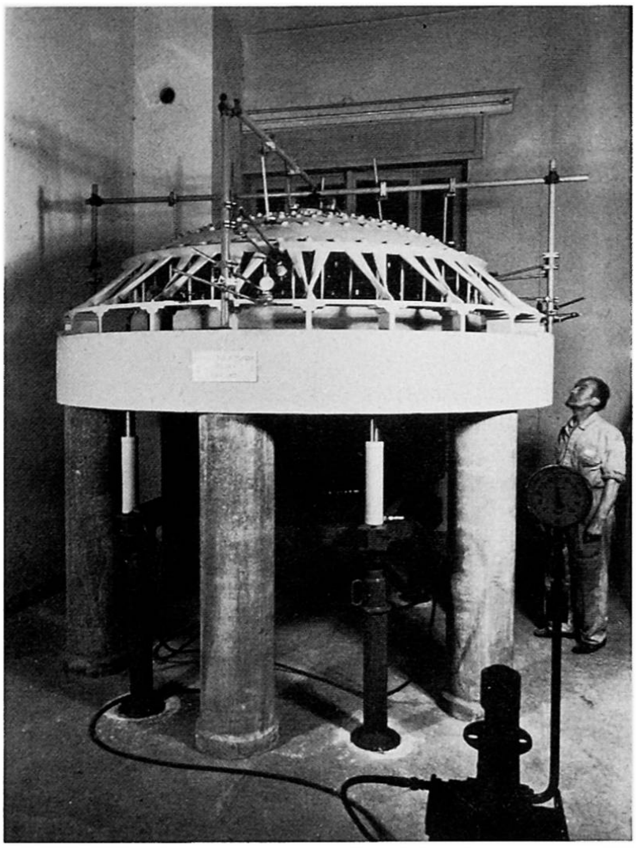

FIG. 1 1:50 scale elastic model of the 130 m dia. circular reinforced concrete shell roof of Norfolk Cultural Center (Virginia, USA). Statical tests.

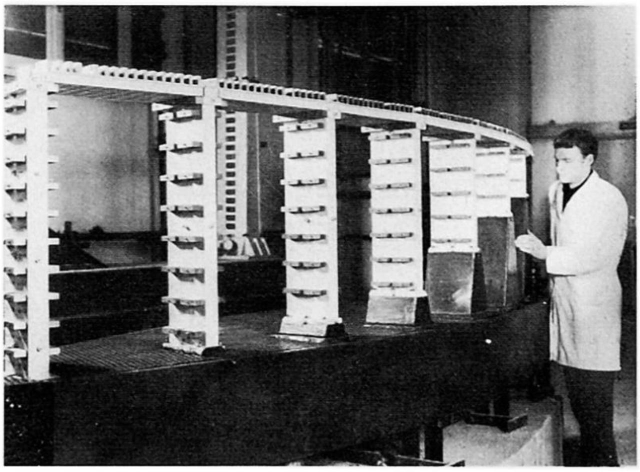

FIG. 2 1:100 scale elastic model of the curved highway viaduct across the Lao river (Calabria, Italy). Maximum height of viaduct piers 80 m. Dynamic tests.

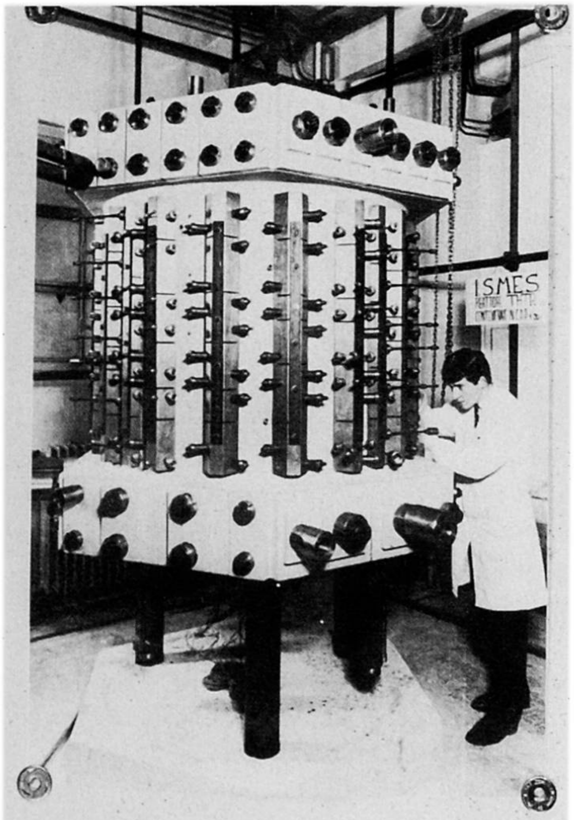

FIG. 3 1:20 scale structural model of the prestressed concrete vessel of the THTR nuclear reactor.

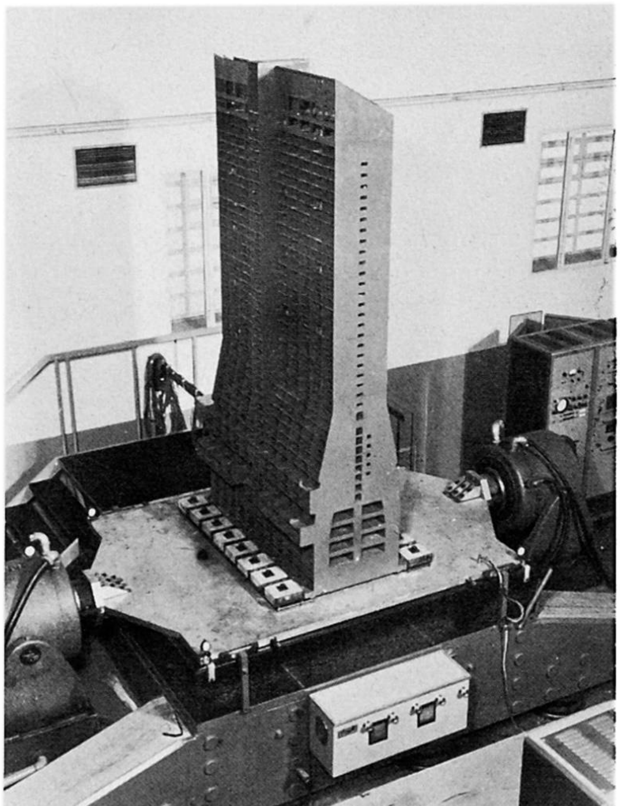

FIG. 4 1:40 scale elastic resin model of Parque Central Skyscraper, Caracas. Dynamic tests taking into account the foundation soil-structure interaction.

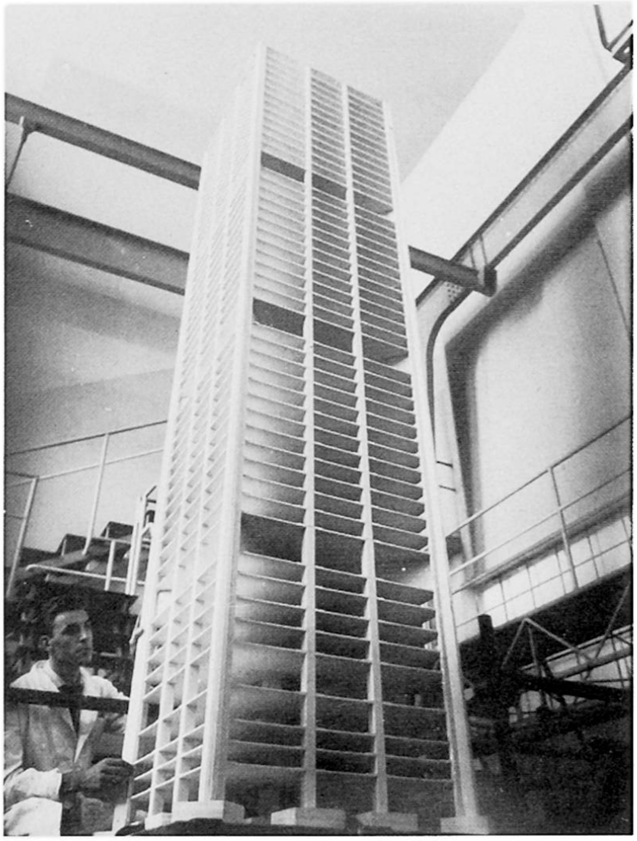

FIG. 5 1:52 scale celluloid elastic model of the 145 m high reinforced concrete building of Place Victoria in Montreal, Canada. Dynamic (seismic) tests.

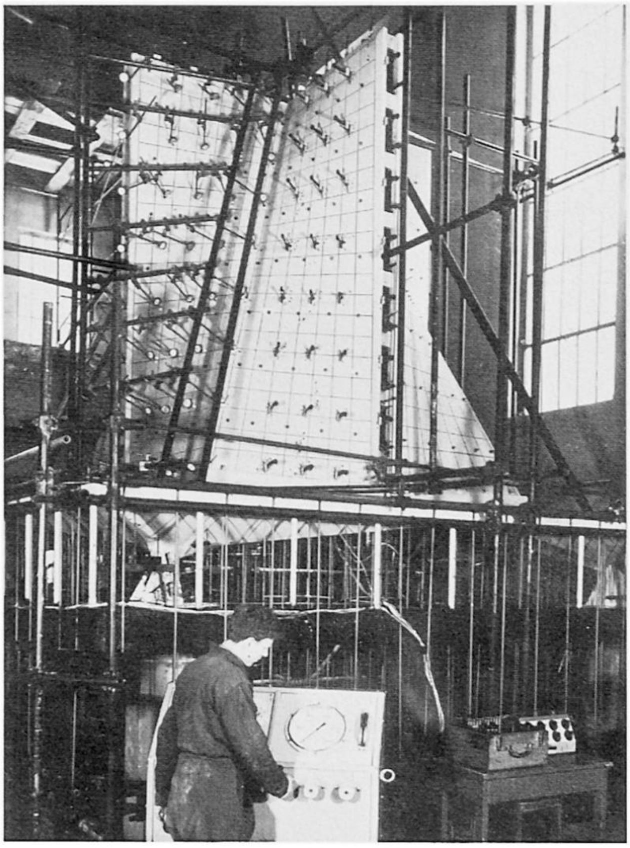

FIG. 6 1:15 scale structural model of the new Cathedral in San Francisco, California, USA, designed by P. L. Nervi. The model is ready for tests to failure.

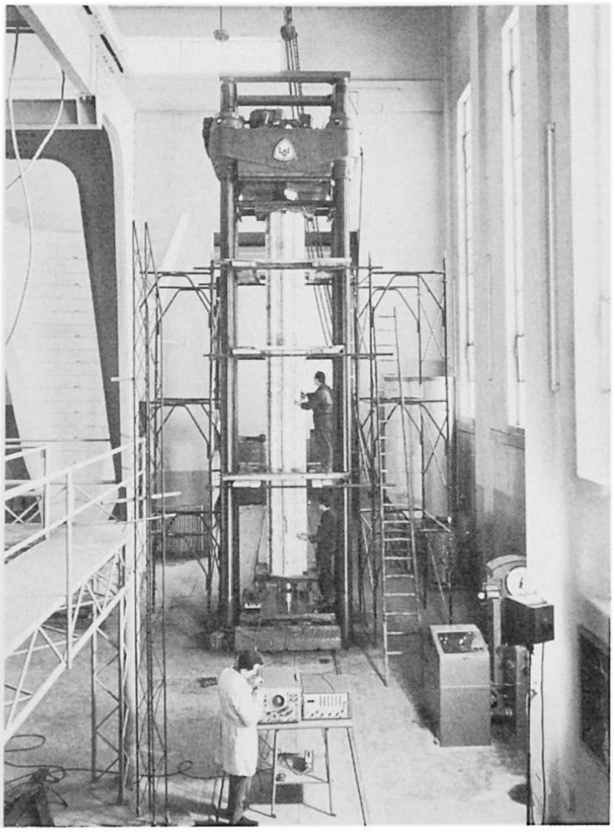

FIG. 7 1:4,7 scale structural model of the main columns carrying the masonry dome of the Cathedral in Milan. The model is ready for the axial compression test.

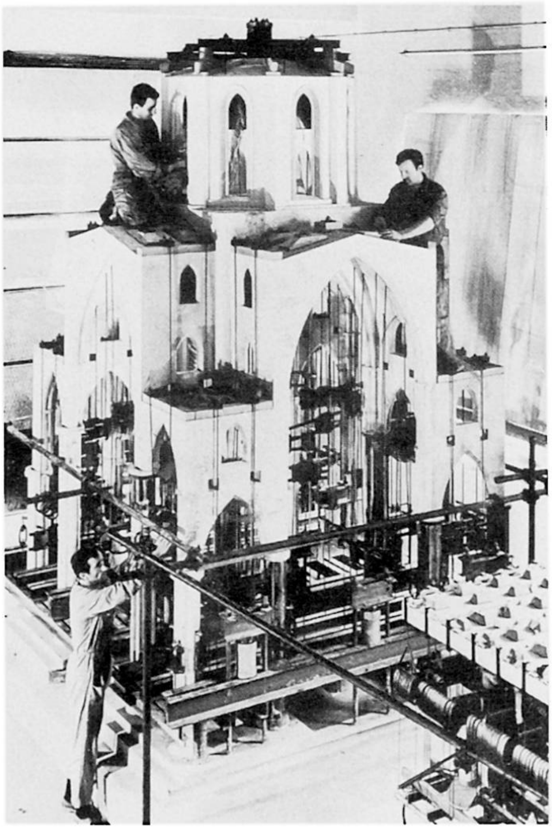

FIG. 8 1:15 scale elastic model of the masonry dome and columns bearing the main spire of the Cathedral in Milan.

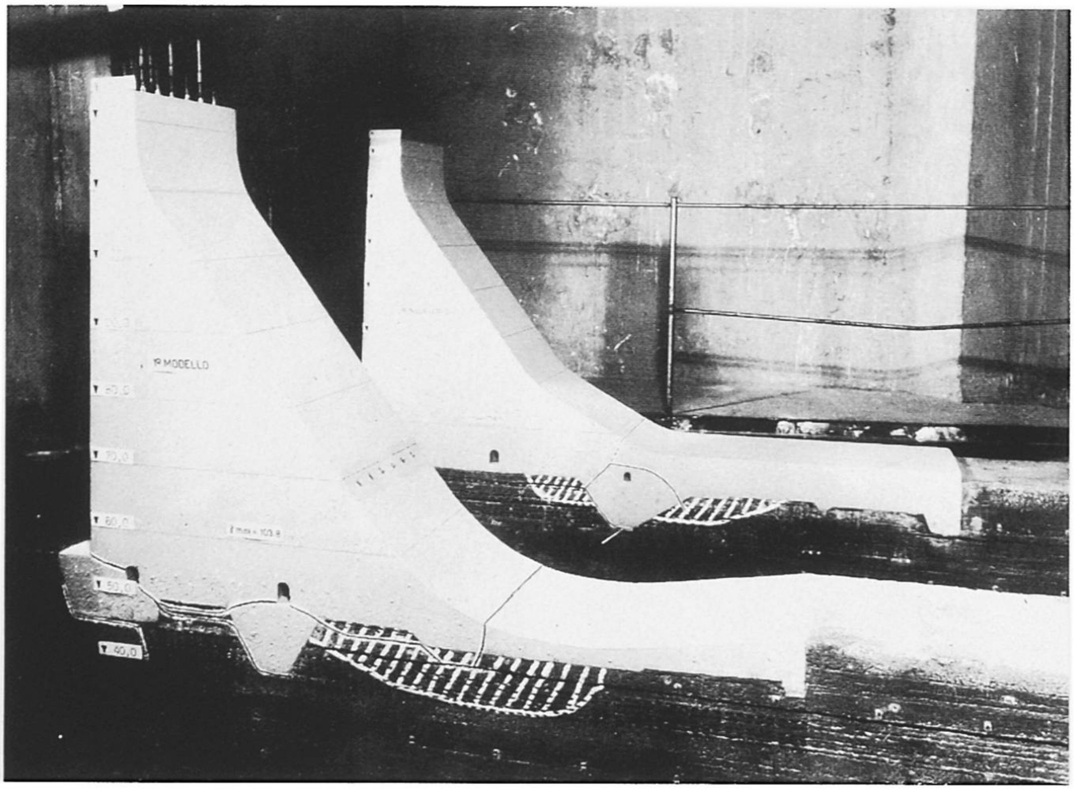

FIG. 9 1:60 scale geomechanical models of a gravity dam in Spain resting on a stratified orthotropic foundation. The tests investigated the effects of the artifices devised to raise the stability of the dam against sliding.

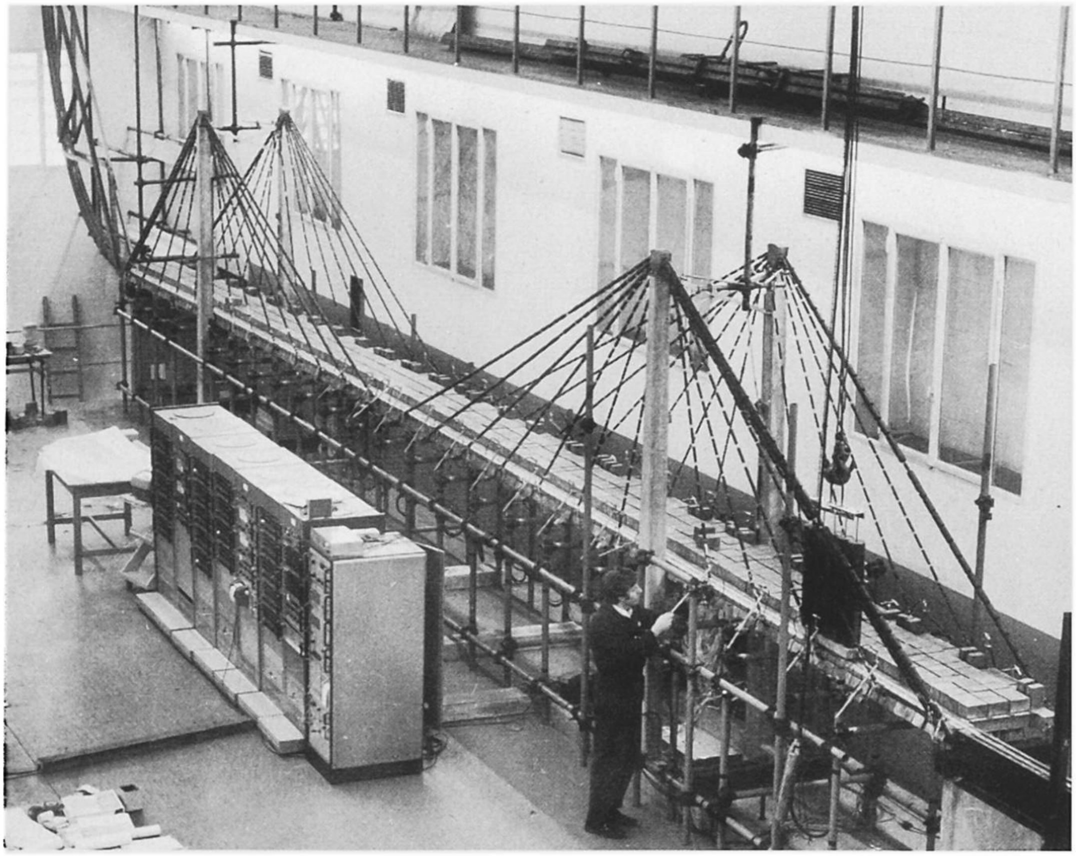

FIG. 10 1:33 scale model of road and railway guyed bridge over the Rio Paranà, Argentina, (complex steel structure). Statical and dynamic tests (running through of a train).