STRUCTURAL PROBLEMS FOR THE MESSINA NARROWS BRIDGE

Leo Finzi, F.A.S.C.E., vCh. I.A.B.S.E., Professor at the Technical University of Milan, Italy

In the past few years a lot of work has been done in Italy on where and how to build the Messina Narrows Bridge. The main problems were the nature and strength of the soil, dangerous currents, winds, faults and relevant earthquakes. At the same time many solutions for a double "one mile" span stayed or suspension bridge and a simple "two mile" span suspension bridge were suggested.
This paper gives a survey of the present state of knowledge with special reference to the technical problems connected with the single span solutions, where aeroelastic stability governs the design of the deck and the cables. On the other hand the 380 m towers are themselves a problem in a heavily seismic area.

1. History.

Italy is a long boot-shaped country. Two miles from the tip of the toe is the island of Sicily (fig. 1).

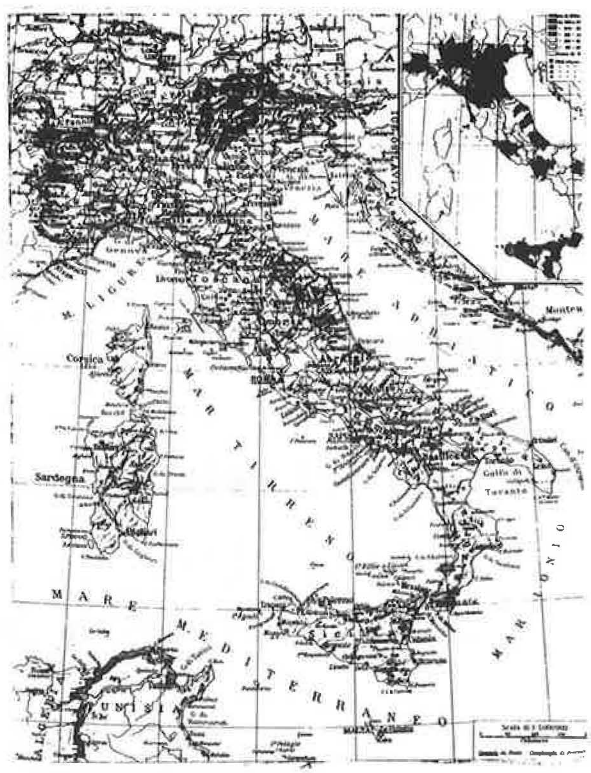
Two cities face each over the Narrows: Reggio Calabria on the mainland and Messina on the island. A ferry-boat shuttle service has so far been the only transportation service across the Narrows both for trains and cars.

The first idea for a permanent connection across the straits is, as far as we know, in a doctoral thesis of 1870 and at that time the cost of the suggested railway tunnel was estimated as less than 40,000 dollars!

However, systematic studies were starded only after World War I, but the decisive step was the foundation in 1955 of the GPM Gruppo Ponte Messina (Messina Bridge Group). In fact the Gruppo Ponte Messina began to analyze, through the collection of the available data and specific experiments, the situation in the area involved in terms of the sea, the air, the soil and the traffic (1).

In 1969 ANAS, the Italian Highway State Agency, together with the State Railways Administration asked on a worlwide basis for ideas to be submitted on possible solutions for the Messina Narrows crossing, both with a highway and a railway.

Figure 1. The Boot of Italy.

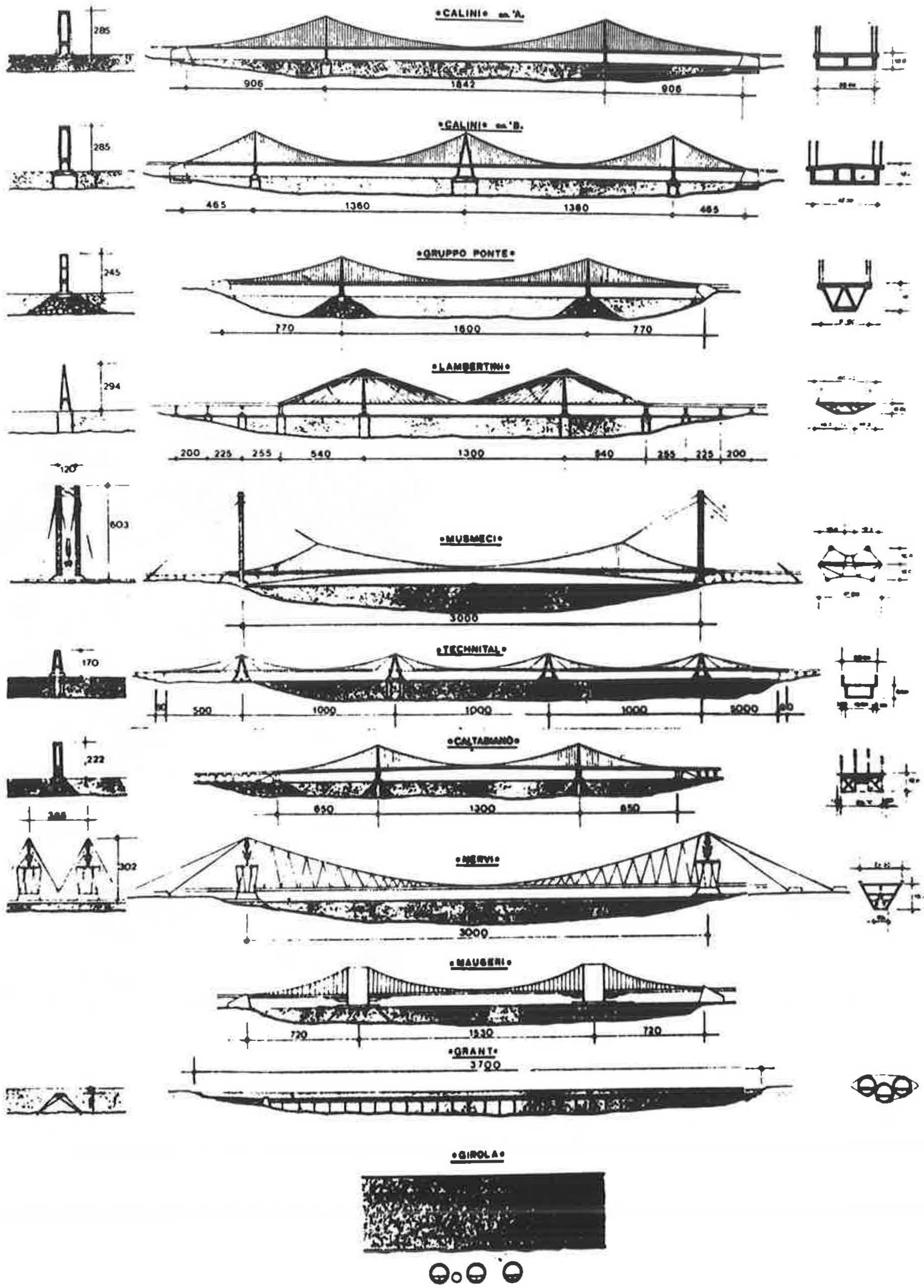


There were 144 participants. Fig. 2 shows the suggestions that were judged the best. Five main possibilities can be distinguished (2) (3).

1. A multispan bridge with intermediate supports;
2. A single 2 mile span bridge;
3. A midwater tunnel;
4. A tunnel buried in the body of a submarine dike;
5. An underground tunnel.

But were all of them really feasbile and, for those that were, which of them were economically competitive?

Figure 2. The 1969 designs.



The Gruppo Ponte di Messina has devoted the last eight years to finding a realistic answer to these questions. In doing so better ideas and solutions were discovered in the field of the double and single span bridges.

2. The Environement.

2.1. The Sea.

Most of the problems in the Messina Narrows derive from the fact that here two different seas, the Tirrenian and the Ionic, meet through a submarine saddle (fig. 3) more than 100 m deep.

The difference of tidal regimes (fig. 4), of temperatures, of density and of depth give rise to a turbulent current going North to South and vice versa four times a day with a speed of more than 3 m sec^{-1}.

In winter waves 4 m high must be considered as possible although in summer the situation is much better.

All through the year many ships of up to 500.000 tons pass through the Narrows and numerous collisions occur, as this Scylla and Charibdis effects is notoriously difficult for navigation.

Figure 3. The sea-bed saddle.

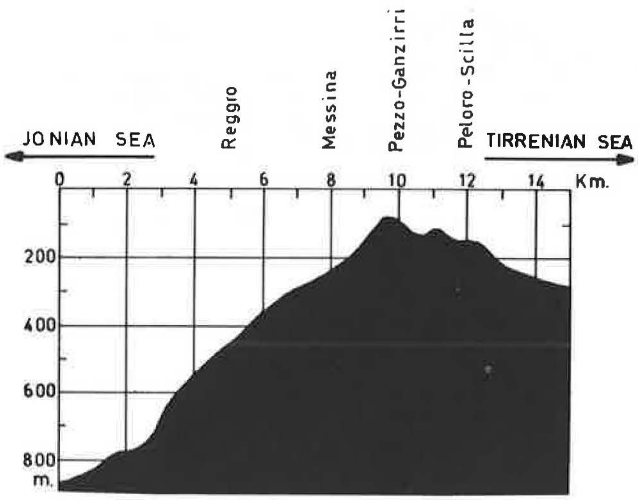
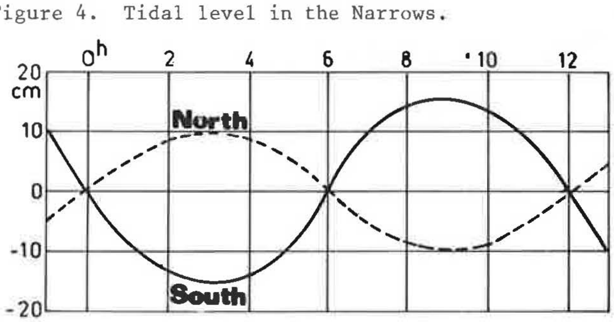


Figure 4. Tidal level in the Narrows.



2.2. The Air.

The wind velocity at ground level is well known through the records of the Air Force and Naval stations, but not so at the level of a possible suspension bridge. For this reason since 1977 many anemometers were placed and are at work at different levels (between the sea level and up to 390 m above) on the existing ENEL transmission towers (fig. 5).

For the moment this seems to indicate a design wind speed of 50 m sec^{-1}.

No tornadoes were registered or are expected in the Messina area.

2.3. The Soil.

It was still very difficult for the geologists and soil mechanics people to get a clear idea of the situation in the straits as it varies widely in the different zones.

Nevertheless, looking at the situation of possible foundations near the coasts and in the middle, it appears like this:

1. Coast: sand and sand with gravel not affected by possible liquefaction phenomena; allowable pressure 50 N cm^{-2};
2. Central saddle: almost 60 m of organogenous limestone on the top, then 25 m of sandstone and finally sand and clay.

In general the bedrock is very deep, more than 300 m under the upper layers.

This is in a highly seismic zone and a possible earthquake of Magnitude 7.5 in the vicinity of the crossing has to be allowed for.

This means an horizontal maximum acceleration at bedrock of 0.5 g with a return period of 1.000 years.

At the same time we have faults that are known, and therefore can be avoided, on the coasts, but that could not and probably cannot be discovered in between.

Figure 5. The 223 m high ENEL transmission towers.

Figure 6. The requested traffic lanes and railway tracks.

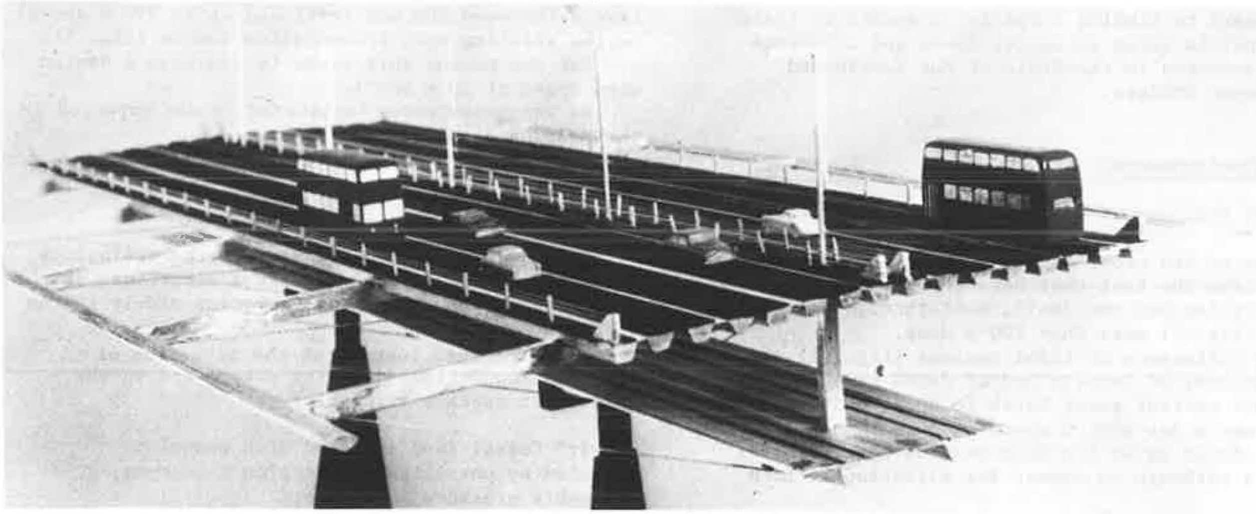


Figure 7. A suggested multispan stayed bridge.

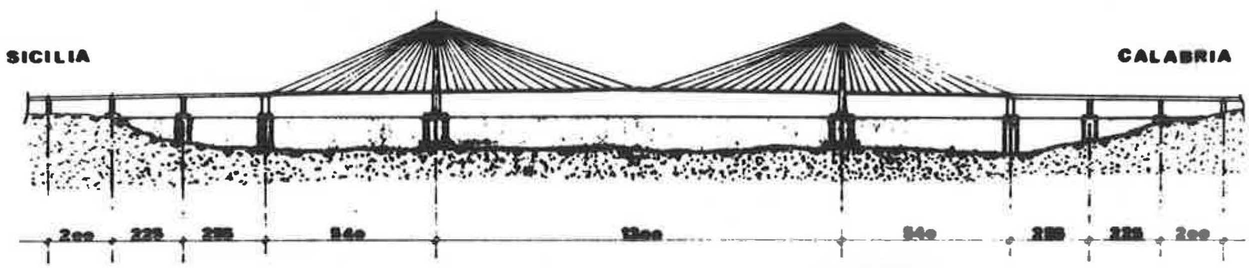
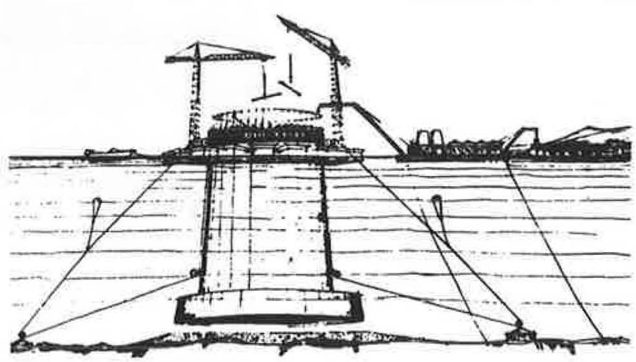


Figure 8. A gradually sinking pier.



Thus a possible pier, island or dike must risk a fault and a consequent possible dislocation of about 3 m.

As we are between two famous volcanoes, Etna and Stromboli, one might think that the Messina Narrows area would suffer from volcanic activity.

This is not the case, as Etna and Stromboli are of very different natures, and no connection between the two has been shown by the volcanologists.

2.4. The Traffic.

A bridge or tunnel accross the Messina Narrows must allow for the following traffic (fig. 6):

3 + 3 highway lanes
2 railway tracks.

Due to the great length of the crossing a mean value of 80,000 N m^{-1} of total service load should be adequate. 50% of that is due to the railway, which also placed severe limits on the maximum slope. A limit of 1.3 - 1.4% must not be exceeded.

2.5. The Temperature.

The temperature of exposed structures will go below - 10° C and over 70° C.

The sea temperature varies between 13° and 24° C during the year.

3. The Intermediate Supports.

If one discards the ideas of a tunnel under the sea due to the length (more than 35 km) and to the problems connected with three faults (one of them across the Narrows) the main choice is between a multiple span bridge or single span bridge.

A multiple span bridge is possible if one can build one or more intermediate supports in a crowded sea lane with a depth of almost 120 m and with variable currents up to 3 m sec^{-1} and more.

There are mainly two possibilities: piers or artificial islands.

First, let us underline that a solution like that shown in fig. 7 (4) with many intermediate piers is ruled out by navigation needs: in fact two channels almost 1600 m wide are required.

That is, only one intermediate support is allowed, and thus the choice is only between a two span or single span bridge.

Many interesting suggestions were given for a possible pier, such as a gradually sinking one (fig. 8) but, besides the enormous difficulties of building it, such monolithic structures are not able to resist earthquakes due to the inertial effects of the surrounding sea water. But a lattice pier like that suggested by G.P.M. (fig. 11) could be earthquake resistant. However, a very sophisticated step by step technique would be needed to erect such a pier in such a sea.

Not such heavy technological problems arise if one thinks of an artificial island in the middle of the crossing (fig. 9).

It is clear that in this case one would need an impressive quantity of rock (approximately 20 Mm^3), but this can be easily obtained from the slopes of the nearby volcano Etna.

Lava, in fact, is an excellent material for building and artificial island, and would have the further advantage of not disrupting the wonderful landscape of the zone.

As a conclusion, one can say that only one intermediate support in the Narrows is permissible and that both a lattice pier or an artificial island are possible.

4. The Double-Span Bridge.

If one decides to have a double-span bridge the length of each span would be approximately 1750 m (fig. 12). This is far beyond the largest span built until now (the Humber bridge in Great Britain with a

Figure 9. The G.P.M. artificial island.

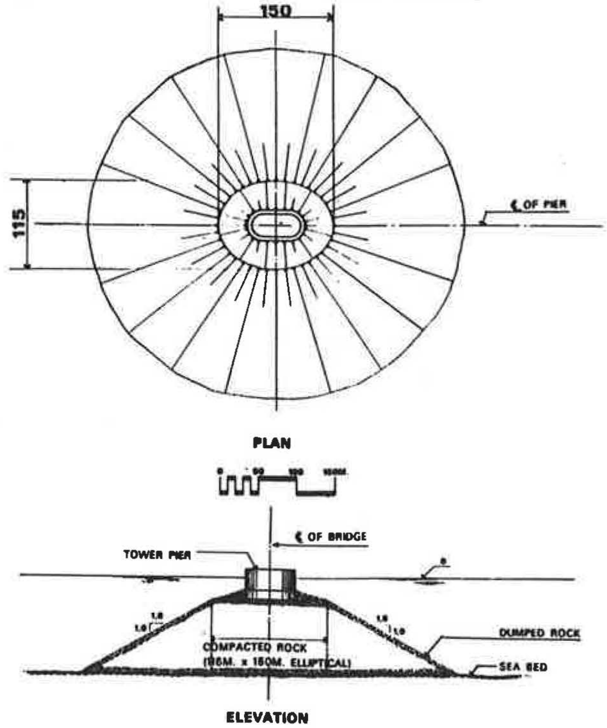


Figure 10. The deck of the double span bridge.

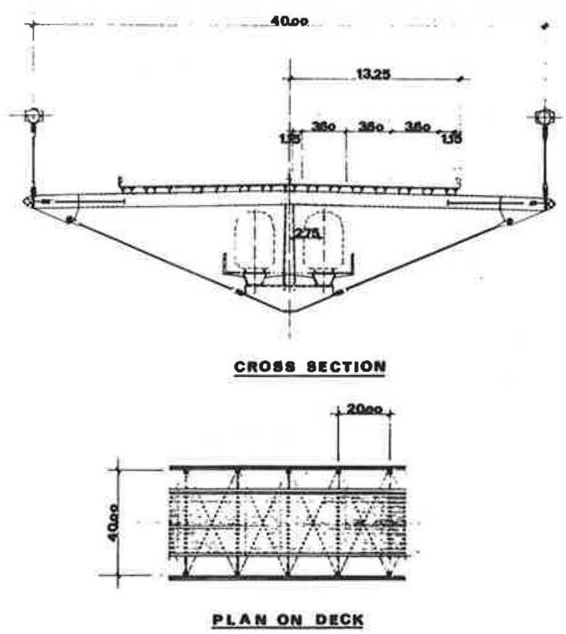


Figure 11. The lattice G.P.M. pier.

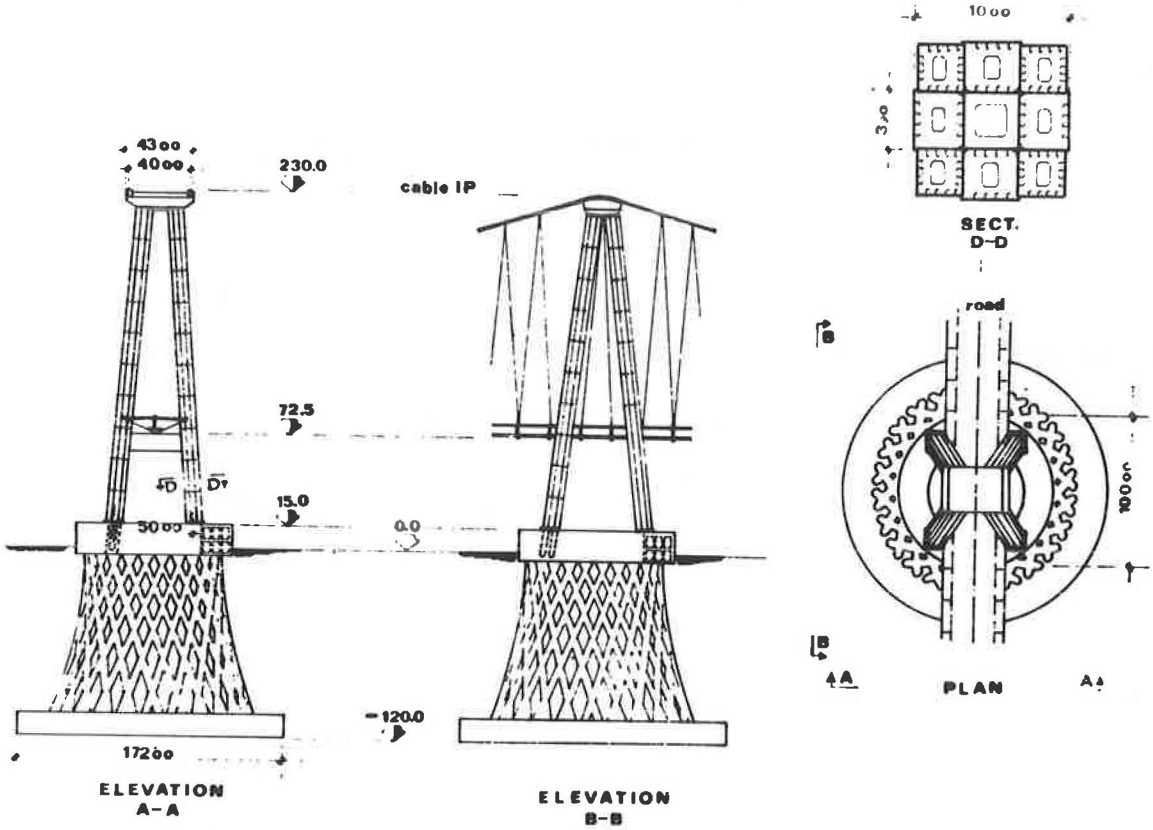


Figure 12. The G.P.M. double span bridge.

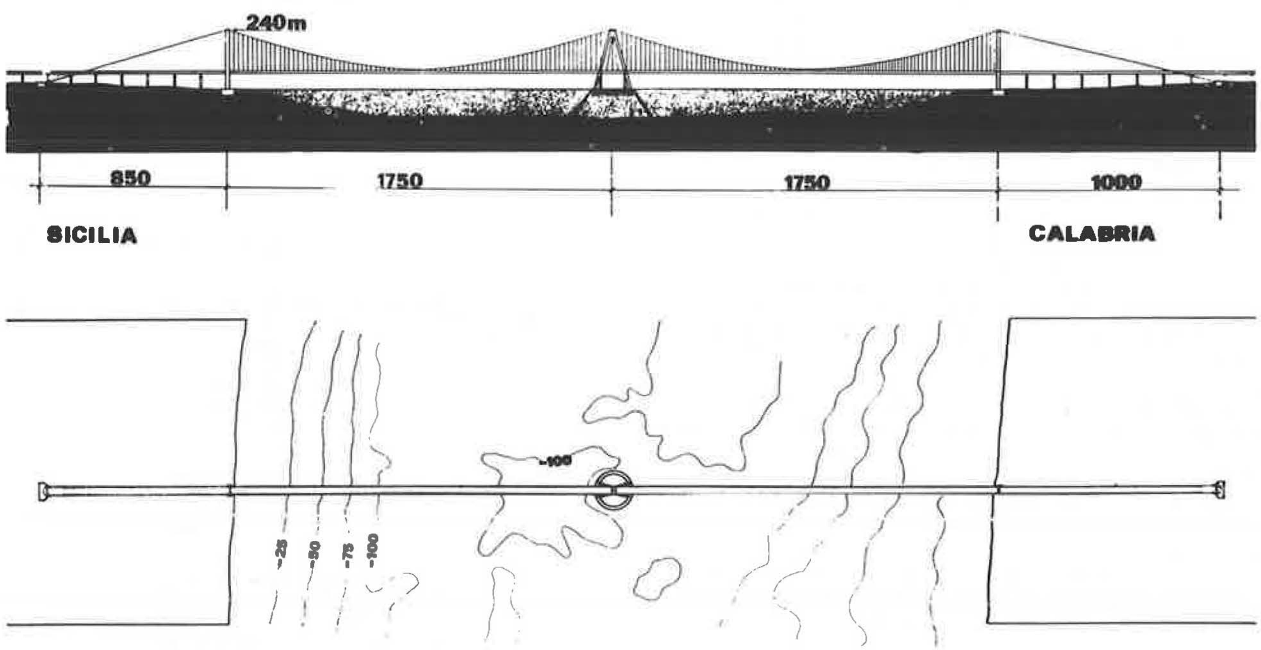


Figure 13. The Musmeci pretensioned hanging bridge.

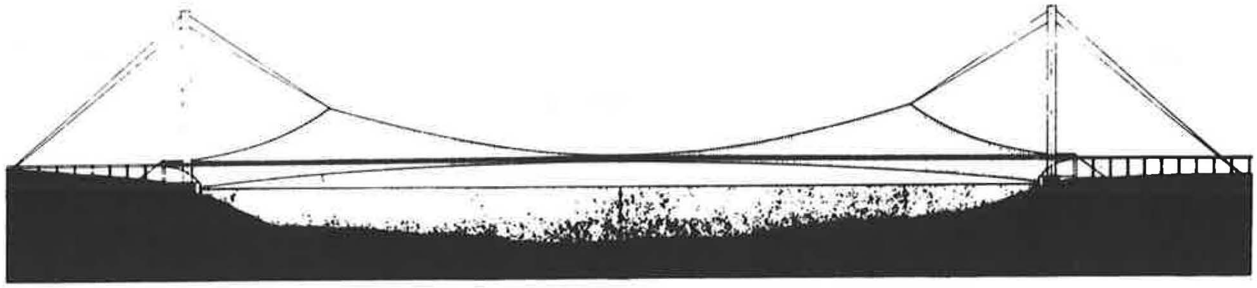


Figure 14. The Musmeci bridge cross-section.

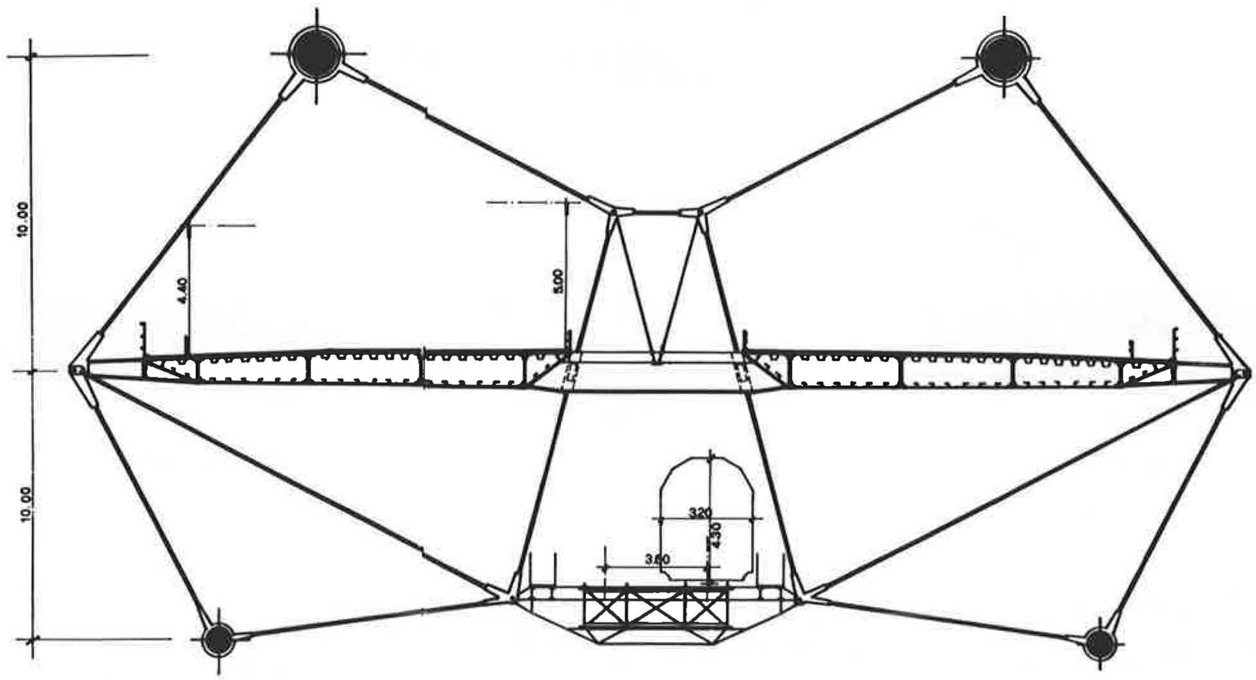


Figure 15. The Danieli hanging structure.

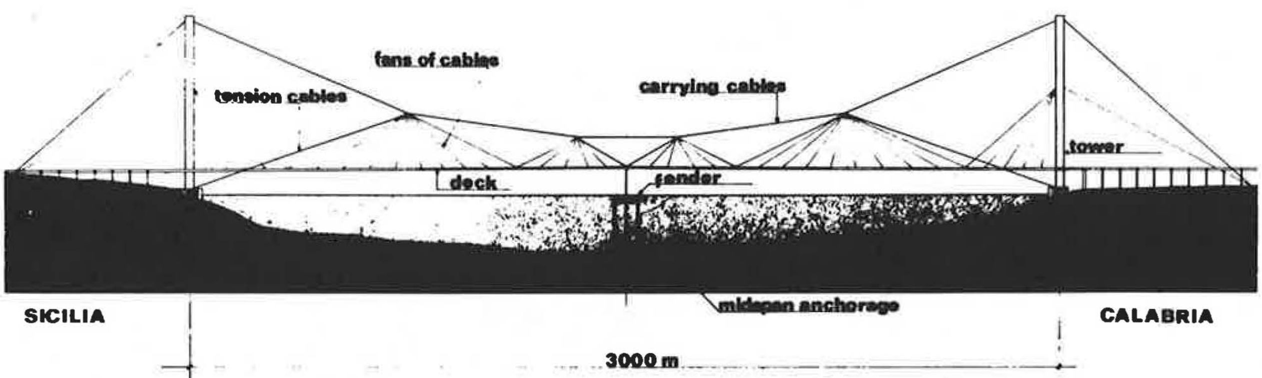


Figure 16. The G.P.M. single span bridge cross-section.

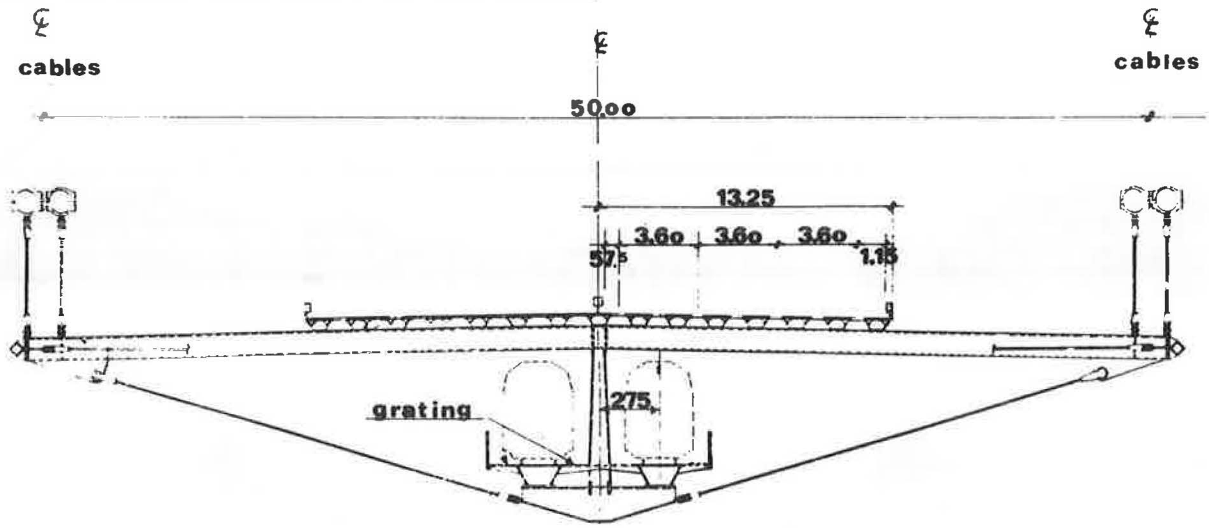


Figure 17. The G.P.M. single span bridge.

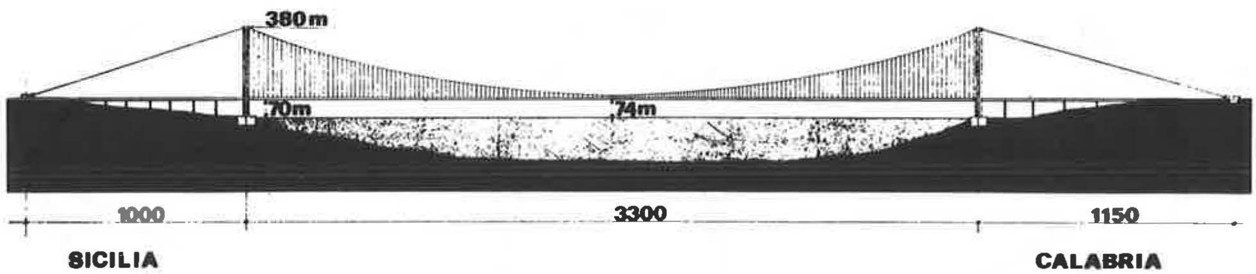


Figure 18. General view of the G.P.M. single span bridge.

central span of 1410 m). Moreover it may be pointed out that it is unusual, at least in Europe, to see heavy trains passing over suspension bridges.

Nevertheless the studies sponsored by G.P.M. have shown that with a ratio of about 12 between span and sag and a moderately expanded cross section (fig. 10) only two 1 m size cables are sufficient and flutter problems can be properly overcome for a design wind speed of 50 m sec^{-1}.

Towers 230 m are required and the central one must be capital delta shaped.

Great help to G.P.M. came both from British experience in this field and from advanced studies done in Italy both through a numerical simulation and experiments in the FIAT wind tunnel.

5. The Single-Span Bridge.

A single-span bridge offers the enormous advantage of not needing a support in the middle of the Narrows, but on the other hand the required span is 3300 m.

The man in the street might think that going from 1410 m of the Humber bridge to the 1750 m of the double span bridge discussed above asks for a reasonable amount of progress in knowledge and technology, but a 3300 m bridge would be far too long.

In our opinion this is not so, but it would be necessary to change the philosophy of design, rather than simply extrapolate present techniques.

A decisive step in this direction was taken by Musmeci. He thought of the simple span bridge more in terms of a hanging structure than as a traditional suspension bridge (fig. 13). That is, he postulated not only carrying cables but also tension cables. A notable advantage in stiffness and a light super structure were the result (fig. 14).

A similar idea was developed by Danieli (5) but he divided the tension cables into two spans, which therefore demanded midspan anchorage (fig. 15).

The above mentioned two proposals had their Achilles heel however, in the aeroelastic stability and in the horizontal stiffness.

In fact avoiding flutter is the main problem for the simple span bridge.

The G.P.M. people saw this clearly and devoted most of their energy to finding an answer to the aeroelastic problem.

A sophisticated numerical simulation was made first and then a series of 1:10 scale experiments on sections of the bridge were performed in the FIAT wind tunnel.

As varying parameters, the ratio between full and empty surfaces of the deck (fig. 16) and the influence of transversally crossed hangers were considered.

Another main advantage of the G.P.M. design was an exceptionally high span/sag ratio (about 12). Such a choice asks for a large amount of steel in the cables(4 cables Ø 1 m) and the percentage influence of the traffic loads is less than 20%. This allows for slopes much less than the maximum required by the Railway Administration.

The result is a bridge like the one shown in fig. 17 where the cross section is spread through a width of 50 m.

An optimal percentage of empty strips and a well calibrated distribution of parallel and transversally crossed hangers allows for flutter wind speed above the fixed limit of 50 m sec^{-1}.

To prevent excessive horizontal deflection the lateral towers had to be split into two independent ones (fig. 18).

As a final result the estimated cost of the single span bridge is less than for the two span bridge or a possible tunnel. That is, it seems the best solution for the Messina Narrows crossing.

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