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Bridges of the 21st Century

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Abstract

Although the future cannot be predicted with certainty, there are a number of potentially useful new bridge concepts and ideas in the offing that give forecasting some credibility. These are discussed first with regard to the repair or rehabilitation of old existing bridges and then with respect to new 21st Century bridges. Three classifications of changes are expected in new bridges: namely minor, major, and radical. Each of these is described in some detail. Finally, examples of some of the more interesting new structures are illustrated, along with their possible locations. It is hoped that this presentation, although speculative, will not only stimulate thinking but lead to the eventual construction of the next generation of bridges.

BRIDGES OF THE 21ST CENTURY

by

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(A Cooperative Organization Sponsored Jointly by the
Virginia Department of Transportation and
the University of Virginia)

Charlottesville, Virginia

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The research reported here, because of the scope, does not fall within the purview of any currently established advisory committee. However, the research was supported by the Council administration in connection with the conceptual research mission.

ABSTRACT

Although the future cannot be predicted with certainty, there are a number of potentially useful new bridge concepts and ideas in the offing that give forecasting some credibility. These are discussed first with regard to the repair or rehabilitation of old existing bridges and then with respect to new 21st Century bridges. Three classifications of changes are expected in new bridges: namely minor, major, and radical. Each of these is described in some detail. Finally, examples of some of the more interesting new structures are illustrated, along with their possible locations. It is hoped that this presentation, although speculative, will not only stimulate thinking but lead to the eventual construction of the next generation of bridges.

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INTRODUCTION

With the new century and the new millennium but a few years away, it is natural for one to speculate on the future. History has shown that forecasting, especially long-range forecasting, is more often wrong than right. Nevertheless, it is believed that the task is worth doing in such a field as bridge engineering because interesting and innovative ideas that are put forth often stimulate thinking. Indeed, a number of new concepts and designs have already been proposed by eminent engineers for future bridges. That fact alone lends credibility to the belief that many of the bridges presented (which includes those by these engineers) will eventually become transformed into reality.

For discussion purposes, bridges will be divided into two basic categories, namely, old and new. In the next century, many of the old bridges constructed in previous centuries will still exist, and these, in ever aging conditions, have to be dealt with. There will also be many new bridges in all parts of the world; some resembling old bridges and others very different. Both old and new bridges will be discussed with regard to new analysis and design procedures, new configurations, new materials, and new rehabilitation and construction methods.

In anticipating future bridge needs in the United States and elsewhere, some physical designs for 21st Century bridges will also be proposed along with possible sites for these structures. Many totally unexpected developments will probably take place, which should only add to the exciting expectations for the next century.

OLD BRIDGES

When dealing with the future of the built environment, it is a common error to disregard that which is now standing, even though much of it will still be there in the future. With respect to the many thousands of bridges now in existence, most will continue to be in service at the beginning of the coming century. As the century moves on, however, fewer and fewer will survive; until only a hand-full remain. Nonetheless, all of those in service will have to be maintained, with a large percentage of them requiring rehabilitation. Not only will old pre-21st Century bridges need rehabilitation, but even many new 21st Century bridges after thirty or so years of service will need rehabilitation. Thus, rehabilitation will be an ongoing problem for the entire century, and needs to be considered in the full context of 21st Century bridges.

The following speculations deal with possible changes in the way rehabilitation will be dealt with in the century to come.

1. Inspection procedures will be more sophisticated and thorough, with better and faster nondestructive detection methods. Many old structures will be instrumented for constant monitoring to signal unsafe conditions. Underwater inspection will be done routinely by small remotely controlled submersibles equipped with a variety of sensors.

2. New computer programs will be able to evaluate the diminished capacity of the structure with a high degree of accuracy and then recommend specific rehabilitation needs and methods using knowledge-based systems (a form of artificial intelligence).

3. Computerized artificial intelligence will be used to recommend the best way to handle such matters as setting work priorities and schedules, handling traffic diversion, and financial arrangements.

4. Although rehabilitation will still be labor intensive and generally customized, component replacement will be favored over local patching. Factory fabrication will considerably reduce field work time, a factor that will become ever more critical.

5. To speed up field work even further, field personnel will be coached ahead of time by means of various simulators involving video, computer graphics and the like. Night and around-the-clock field work are likely to be commonplace.

6. Polymerized concrete for deck replacement will become more popular as the polymerizing process becomes easier to do. Such concrete will greatly out-perform all conventional concrete in strength, durability, and chemical resistance.

7. Adhesives will play a greater role in strengthening and repairing weak elements by laminating good material over deteriorated material.

8. Special ceramic tiles will be used in some situations as bridge deck overlays. These durable, textured panels will be highly resistant to the effects of almost all kinds of service and environmental conditions.

9. New chemicals, both applied to the surface and injected, will be used to preserve and strengthen old concrete.

10. Hazardous repair work, such as underwater activities, will largely be done by remotely controlled tethered robots. These will be equipped with video and other sensors and directed by human operators.

11. Because of the high demand for fast, economical rehabilitation, an array of specialized machines will be developed and used to assist in such work.

12. Numerous old vehicular bridges will be converted for alternate uses instead of being destroyed. These will be moved to new sites and converted into facilities such as restaurants, museums, and retail shops.

Since rehabilitation is cost effective for only so many years (estimated to be about 30), eventually, even rehabilitated bridges will be replaced with new ones. Exceptions would be made with regard to a relatively few structures deemed to be historic. These will be rehabilitated possibly more than once and then perhaps totally rebuilt. Those chosen to be rebuilt will retain essentially the same visual qualities as the original, but in part will be made of different 21st Century materials. For example, steel may be replaced with a graphite composite and steel-reinforced concrete may be replaced with a fiber-reinforced ceramic.

Overall, rehabilitation will require the expenditure of billions of dollars annually in the United States alone in order to maintain the transportation infrastructure. Although not a glamorous aspect of engineering, rehabilitation will clearly remain an important and critical need. Unfortunately, it is not amenable to quick and easy solutions, so a sustained level of funding as well as innovative approaches will be required to deal with this ongoing problem effectively.

NEW BRIDGES

It is a virtual certainty that many thousands of new bridges will be built in the next century. Population expansion, demographic shifts, economic pressures, and general obsolescence are but a few factors that will generate the need for new bridges. These structures will take many forms and will be made of a variety of materials. A great many of their features will be different from those of 20th Century bridges. For discussion, these changes are classified as minor, major, and radical, and are described in the following sections.

Minor Changes

The majority of changes that are certain to take place will be of a minor nature. These are relatively small changes occurring incrementally over a period of time; whereas in a span of fifty or more years, the overall changes will be large. Only the relatively small, short-term incremental changes will be discussed here. Some of those that may be expected are as follows:

1. Extensive use will be made of computerized knowledge-based systems (a form of artificial intelligence) in decision-making. Particularly in the initial design phase, these systems will help determine what type of bridge is best suited for a particular site.

2. There will be universal conversion to SI metric units. At the same time there will be a movement to standardize and unify bridge specifications in many countries of the world.

3. Commonly used concrete will gradually increase in strength to over 100 megapascals (15,000 psi). This will be achieved through the use of a combination of liquid, powder, and fiber additives.

4. Low corrosive steels with strengths in excess of 700 megapascals (100,000 psi) will be in everyday use. Such steels will reduce the size and weight of members, as well as reduce maintenance costs.

5. There will be some use of glass fiber tendons as a replacement for steel in reinforced concrete and prestressed concrete. Their use will reduce corrosion problems, especially in bridge decks.

6. New designs will reduce the number of "open" joints in bridge decks. Maintenance costs associated with joints consequently will be minimal.

7. Adaptable, programmable machines will allow for customized prefabricated components for substructures. These machines will take field measurements in situ and fabricate foundation components to fit each specific site.

8. Field personnel will be directed by on-site video, computerized instructions, and computer graphics as much as by paper drawings. These electronic devices will provide personnel with real-time links to the client, designers, inspectors, and suppliers.

9. A high percentage of structures will have built-in instrumentation at critical locations to monitor performance. The safety of a bridge will thereby be increased through the early detection of anomalies that might lead to failure.

10. Some application of solar energy will be used to prevent ice formation on bridge decks. These particular bridges would have an array of solar collectors mounted on masts flanking the bridge. Through solar-produced electricity stored in new superconductive batteries, such collectors will heat the deck surface as needed.

11. There will be an increase in design-build contracts. This practice, common in Europe, will gain acceptance in the United States as

well. As a result, bridges will be built more quickly, at lower cost, and often with more innovative features.

Major Changes

Whereas virtually all new bridges will incorporate some minor changes (such as those previously listed), many will also incorporate changes of larger magnitude or of greater importance. Some of these still require further research, but their successful development would open up new approaches to bridge design and construction. Many of these major changes would alter the appearance of bridges as we now know them and contribute significantly to their effectiveness.

Some of the major changes possible are as follows:

1. A number of new high performance materials will be developed to replace ordinary reinforced concrete in decks, such as:

a. Lightweight fiber-reinforced polymerized concrete. Using a combination of polymerization and fiber reinforcement, all conventional steel reinforcement could be eliminated. Through further research, ways will be found to simplify the polymerization process of in situ bridge decks. Construction of a deck would thus be greatly facilitated by reducing the extensive labor needed to place the large number of reinforcing bars.

b. Fiber-reinforced ceramic panels. This new shock-resistant material would be factory-manufactured in modular form and assembled rapidly on the bridge. Such panels will have exceptionally high strength and durability.

c. Sandwich panels in various combinations of materials. Depending on their function, they could be made of metal skins and plastic core, or metal skins and lightweight concrete core, or polymerized concrete skins and cellular concrete core, or metal top skin, glass-reinforced plastic bottom skin, and foam plastic core. An added wearing course over all top metal skins would be factory-bonded to the panels.

d. Extruded rib-stiffened steel or aluminum plates. Such plates would be produced without any welding (as now required) and would be made in a variety of sizes and shapes.

2. Fiber-reinforced polymerized concrete (without conventional and reinforcing steel) will be developed to a point where prefabricated structural members will be extruded rather than cast. Numerous optimally shaped and hollow configurations will be produced at relatively low cost.

3. There will be increased use of laminated and composite materials in the superstructure. Examples include one-piece laminated metal

joints, graphite composite cables, unitized glass-reinforced plastic bracing, and composite bolts and other fasteners. These materials will have better performance characteristics than traditional solid materials.

4. Chemical prestressing will partially replace mechanical prestressing. Electrical stimulation of the chemicals added to the concrete mix will activate the system as well as control the amount of prestressing.

5. Monocable suspension bridges will replace twin-cable bridges. A suspension system with one overhead cable instead of two will be used for all but the longest suspension bridges because of its improved economy and appearance.

6. Many urban expressways will be viaducts elevated 30 meters (100 ft) or more above ground level, spanning over existing buildings. In some cases, the buildings themselves will serve to support these bridges. As needed, helical ramps to these expressways will provide access from ground level.

7. Difficult road geometry in many places will necessitate the need for long-span bridges curved in plan in both "C" and "S" configurations. Such structures, which are subject to high torsional forces, will incorporate various kinds of new deck and support systems. Cable-stayed, hollow girder, and truss systems will all be tried.

8. Metal bridges made of new composites and alloys (prefabricated in segments) will be assembled on the site somewhat like segmental concrete bridges. Strengths and spans, however, will be considerably larger than for such concrete bridges.

9. Several reinforced plastic bridges will be built. Largely experimental, these structures, however, will not be widely used except as pedestrian bridges.

10. Active control systems for long-span bridges will begin to be used. Special tendons incorporated into various parts of the structure would respond to static and dynamic deformations and strains in such a way as to substantially reduce deformations and stresses. This would be done by having sensors detect initial structural movement. This information would then pass through an on-board computer, which in turn would relay appropriate signals to force actuators attached to the tendons. Long-span girder bridges, cable-stayed bridges, and suspension bridges will have numerous such tendons built into them, enabling these structures to span farther and with less material.

11. Several super-span bridges of up to 5 kilometers (3 miles) free span will be built. These will be suspension bridges with active control systems of various types. Some systems will act only as dampers and others will exert more complete control. For lateral stability, the main suspension cables will slope inward towards the deck (as well as downward). A few of the larger spans will be built as two tandem

bridges, thereby enabling the twin structures to mutually strengthen each other by means of cross braces.

12. Various forms of robots will be used in bridge construction. Initially, industrial robots will be used in factory fabrication of components, particularly in joint assemblages. As robotic development continues, field robots will be used, especially for hazardous situations. These will generally be remotely controlled by human operators, but some will be "smart" enough to operate on their own. Most will need to have two coordinated arms to perform the tasks required. They will also need sophisticated sensors as well as some degree of artificial intelligence. Field connections made by robots will need to be specially designed for simplified assembly and will look quite different from conventional connections.

13. Ornamentation of bridges will again become popular. As the public tires of the bare-bone look of bridges, esthetic ornamentation will be seen on many bridges, particularly urban ones.

Radical Changes

The radical changes that are expected for 21st Century bridges are those that will dramatically alter the appearance of bridges as we now know them. Although many of the minor and major changes previously noted will probably also be incorporated into these designs, only the radical changes themselves will be described here.

1. Kinetic structures. Pioneered by the military, various kinds of rapidly deployable and relocatable bridges will be adapted for general use. These structures will look more like large machines than traditional bridges in that they will employ motors, rotating members, telescoping arms, and the like. Special launch vehicles will be used for erection, rather than ordinary construction equipment. For storage and transport, they will be made to self-compact. Many will have the feature of adapting to a variety of span lengths and load conditions. Some of these kinetic bridges will be used for emergency replacement of collapsed bridges, but most will be used to temporarily bypass the many old structures undergoing extensive repairs. After use at a given location, they will be re-deployed for service at a different location.

2. There will be a number of underwater bridges. In the past, bridges have been constructed either above the water or floating on the water. New types of bridges will be built, suspended part way between the surface of the water and the water bottom. They will resemble tunnels, but instead of being held up by firm earth materials, they will be held down by self-adjusting cables anchored to the soil or rock at the water bottom. When positioned deep enough, they will be immune from surface turbulence resulting from wind and passing ships. Streamlining of the bridge will minimize deep current effects, and the weight of the structure will be offset by the buoyancy of the water. Such underwater

bridges will require relatively little support structure and will be used primarily for long water crossings.

3. Stress ribbon bridges, previously used only for pedestrian structures, will be used for vehicles. Under limited conditions, prestressed concrete ribbon bridges will be used for spans up to 150 meters (500 ft). Problems of anchorage and vibration will prevent them from being used very widely for vehicles, however.

4. Multiuse bridges will be seen again. The pressures of urban growth will require that many bridges serve not only transportation needs but also habitational, commercial, and leisure activity needs. Such bridges will be designed completely differently from conventional ones and will take on the mantle of architecture. Usable space will be created in a variety of places along the bridge, such as on the superstructure, in the piers and abutments, and at the bridge approaches.

5. High-art bridges will make an appearance. A number of international bridge competitions, calling for a new 21st Century look, will be held for bridges at various prestigious locations around the world. Imaginative entries by artists and architects will tend to dominate the winning submittals. As a result, their esthetically exciting and bold designs will create a new vision of bridge structures. Most of these will convey a strong sculptural image, guided more by art than technology. Some will also display a daring use of color. However, engineering difficulties and the high cost of such bridges will keep their numbers low.

Examples of New Bridges

To give form to some of the preceding forecasts regarding 21st Century bridges, some examples of possible new designs are shown here in sketch form. The designs presented are in part original and in part influenced by others. Acknowledgements are made as appropriate. Also noted are possible sites where such bridges might be built.

BIBLIOGRAPHY

Zuk, W., A Forecast of Bridge Engineering 1980-2000, Virginia Highway and Transportation Research Council, VHTRC 79-R55, July 1979.

Zuk, W., Kinetic Bridges, Virginia Highway and Transportation Research Council, VHTRC 81-R6, July 1980.

Zuk, W., A Forecast of Bridge Engineering 1980-2000, Transportation Research Board, Record #785, pp. 1-6, 1981.

Zuk, W., Bridge Engineering, A Continued Evolutionary Progress, The Military Engineer, Vol. 73, #474, pp. 254-258, July-August 1981.

Zuk, W., A Long-Range Forecast of Transportation in Virginia, Virginia Highway and Transportation Research Council Report, March 1982.

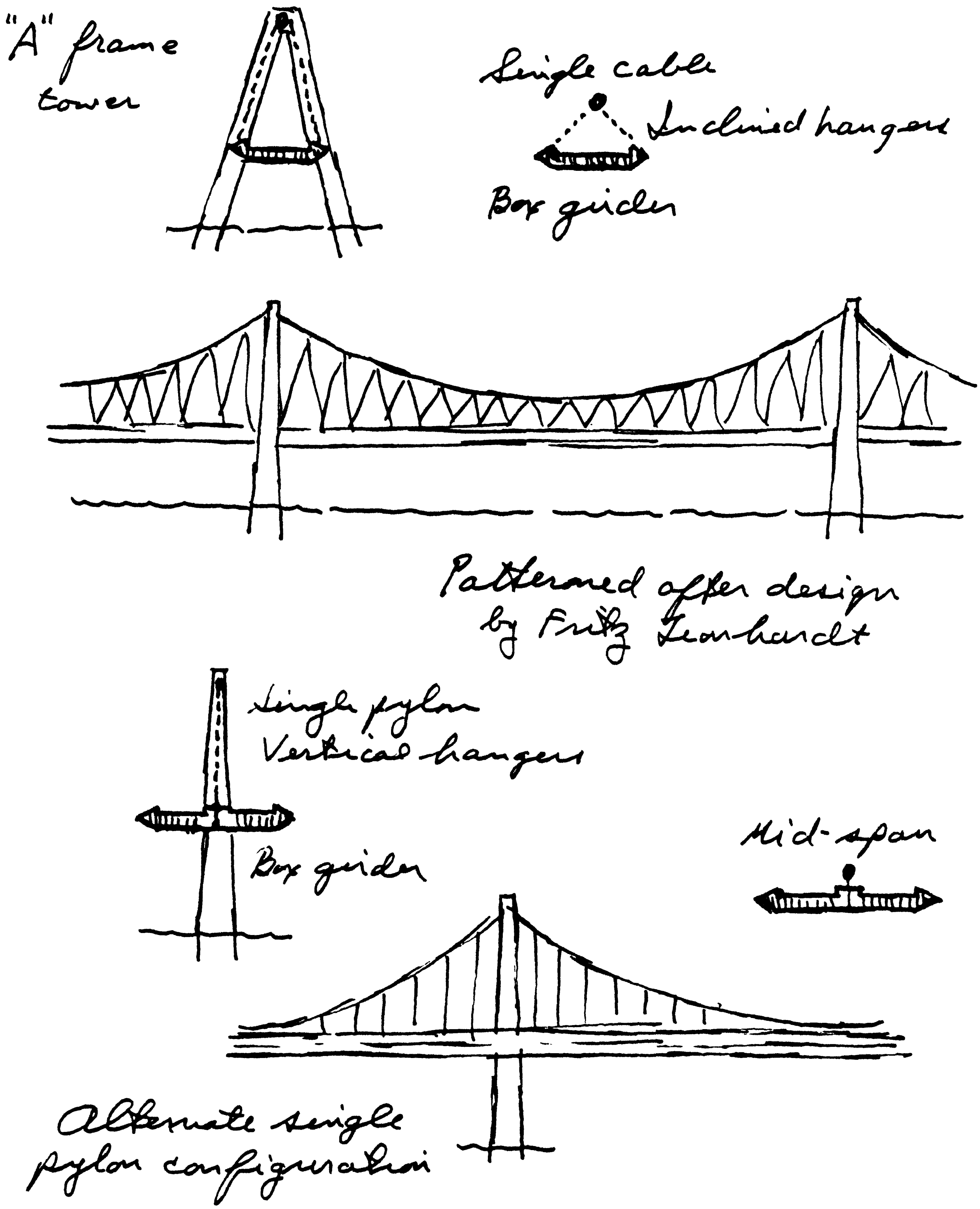
Zuk, W., Architecture, The Century Beyond Tomorrow, 1985.

Zuk, W., Structures Beyond Tomorrow, American Society of Civil Engineers Proceedings of Civil Engineering in the 21st Century, pp. 245-249,, Nov. 1987.

Zuk, W., Structures Beyond Tomorrow, American Society of Civil Engineers, Journal of Professional Issues in Engineering, pp. 344-347, July 1988.

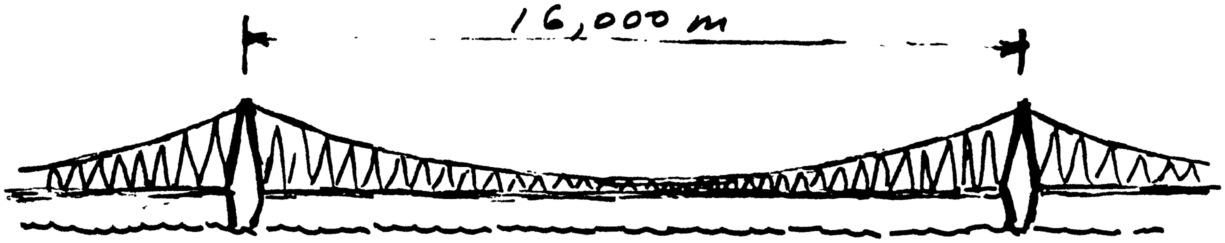
Zuk, W., Notable Unbuilt Bridges, Virginia Transportation Research Council, VTRC 88-R28, June 1988.

Zuk, W., Notable Unbuilt Bridges, American Society of Civil Engineers (Proceedings available May 1989).

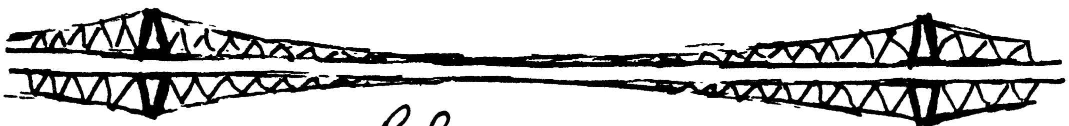


Monocable Suspension Bridges

Possible site: Hong Kong - Kowloon



Elevation

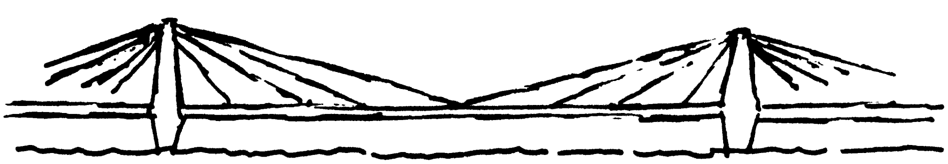


Plan

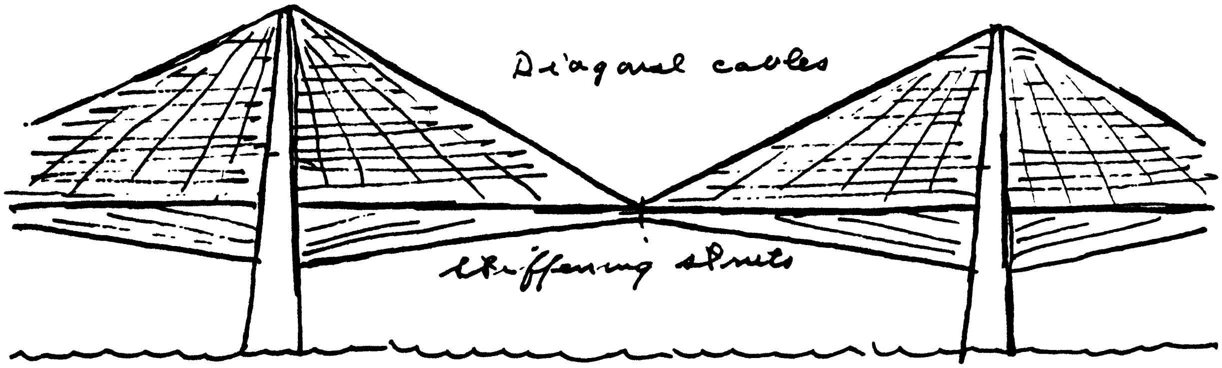
Tower

Super-Span Suspension Bridge

Patterned after designs by
Lev Zetlin & T. Y. Lin
Possible site: Messina Strait,
between Italy & Sicily



Similar concept for long span
cable stayed bridge, using support
towers with inclined arms.



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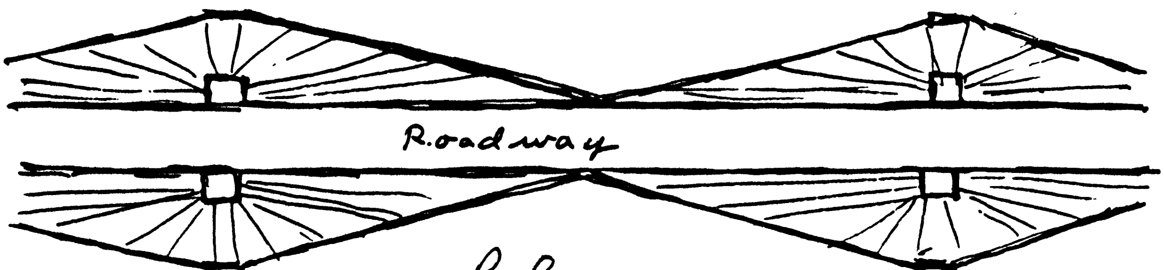
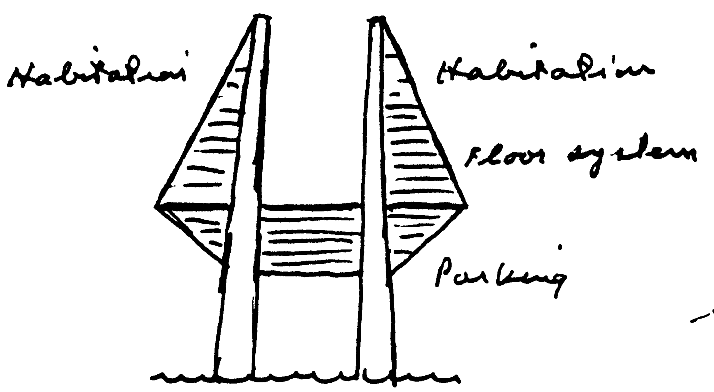


Plan

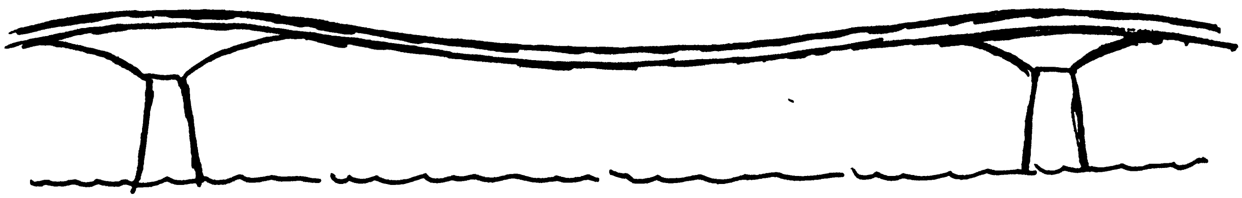


Section at support

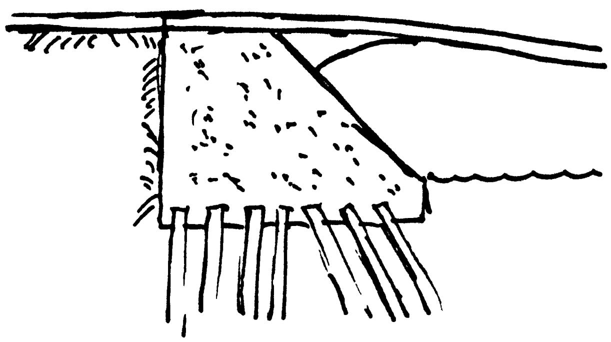
Section at mid-span

Multiple Use Cable Stayed Bridge

Possible site: East River at New York City

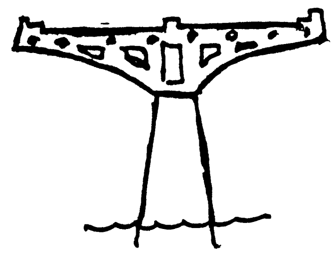


Elevation



End anchorage

Hollow concrete box section



Section at support

Solid concrete slab

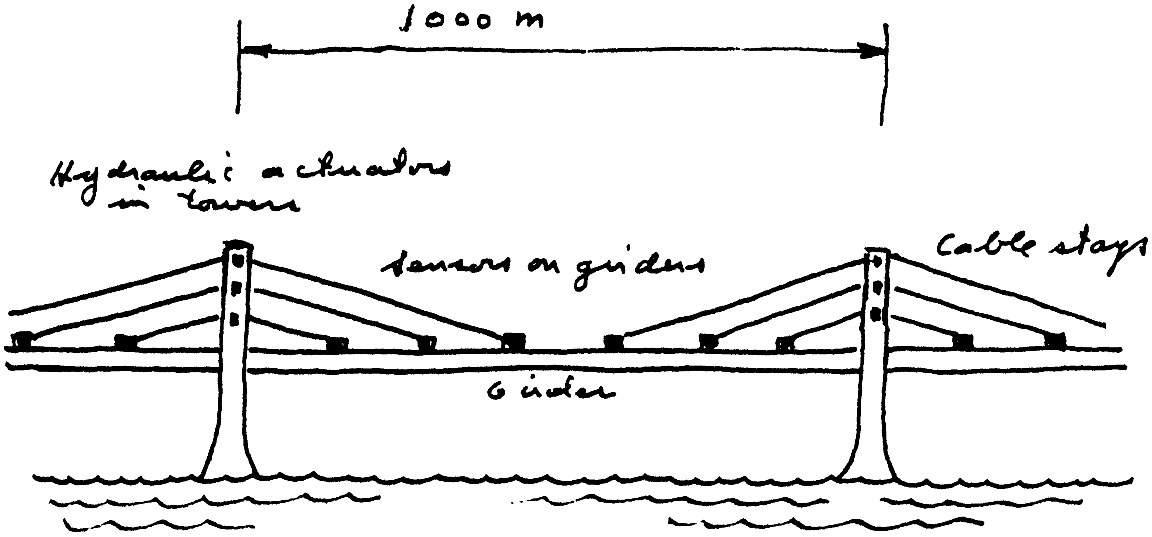
Draped prestressing tendons

Section at mid-span

Stress Ribbon Bridge

Patterned after design by Ulrich Finsterwalder

Possible site: Multiple span crossing of the Amazon River in Brazil



Actively Controlled Bridge

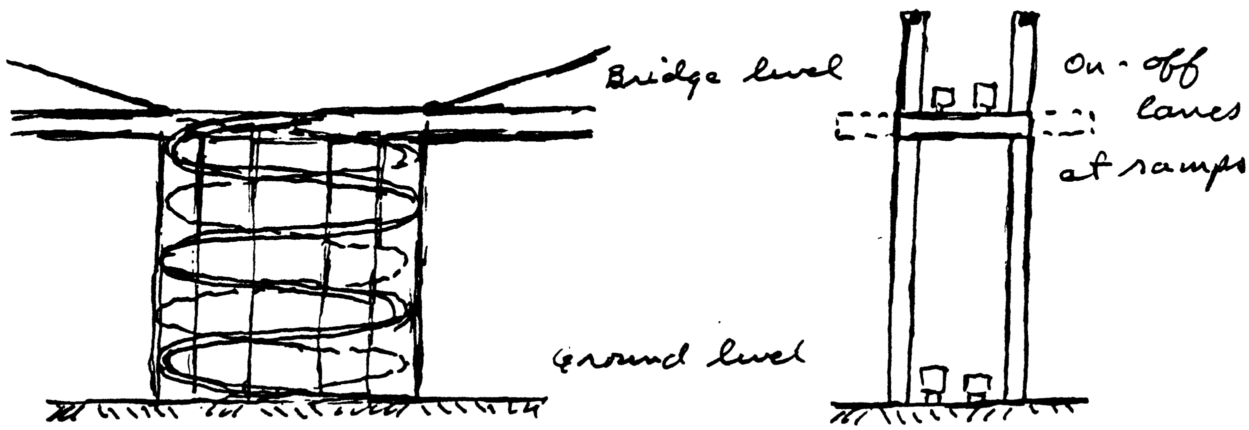
Actuators would reduce dynamic stresses in girders

Possible site: Bering Strait between Alaska and Siberia

Concept of a bridge across the Bering Strait by T. L. Lin

Active control concept by W. Zuk

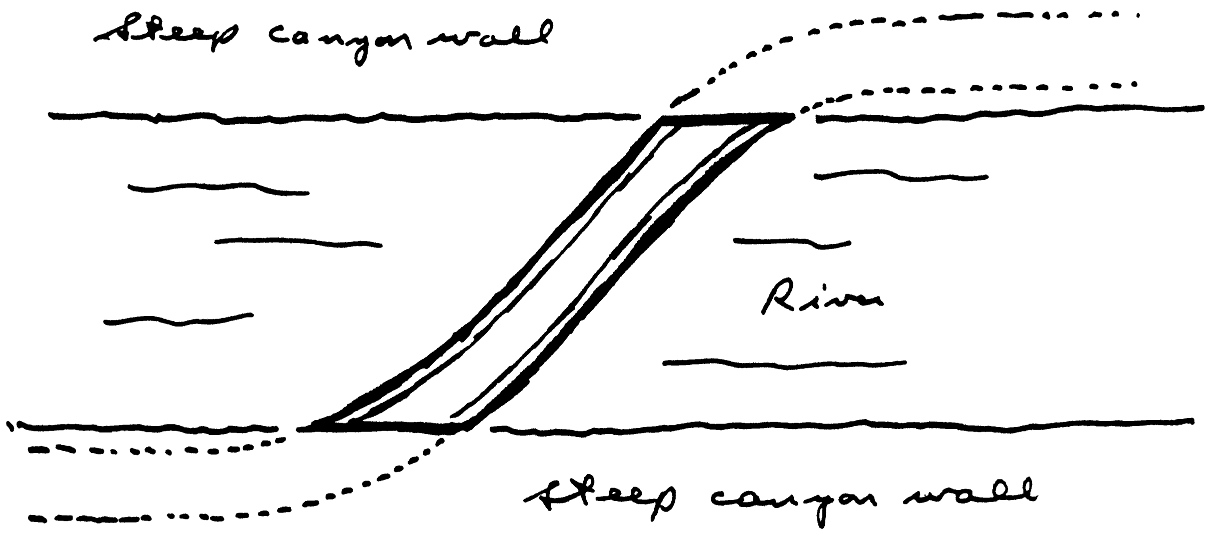
Quadruped towers at street intersections



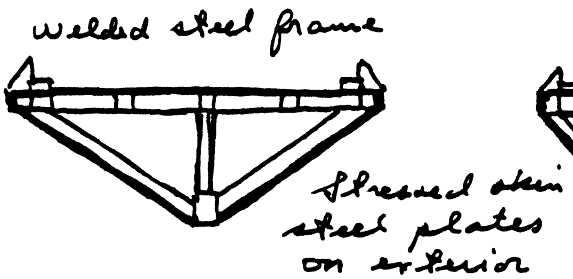
On-off helical access ramps

High Level Urban Expressway

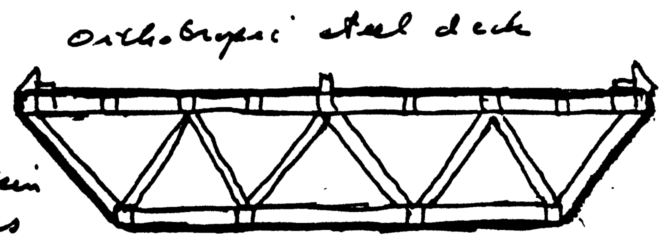
Possible site: Boston



Plan



For narrow roadway

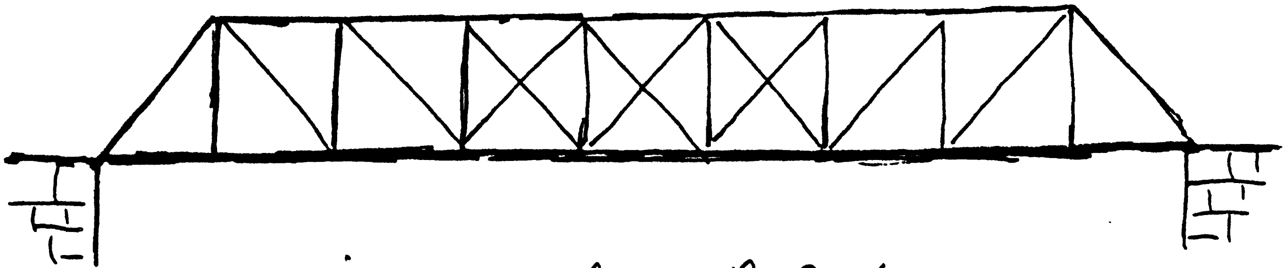


For wide roadway

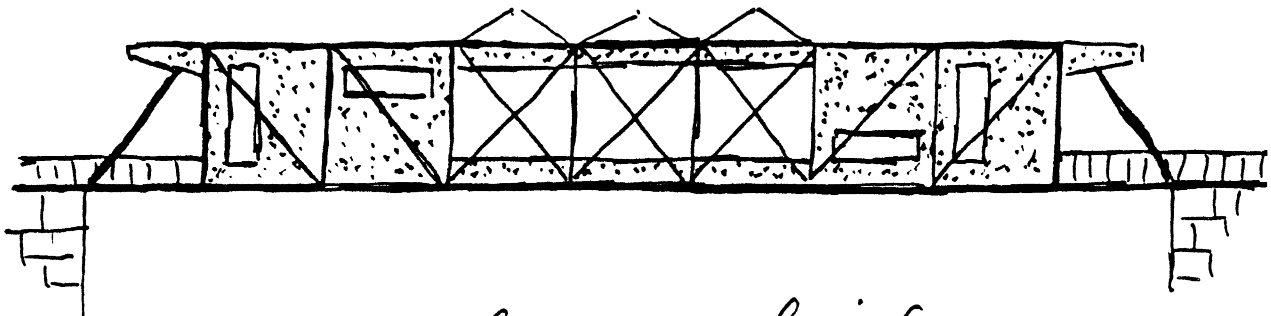
Curved box sections

"S" Bridge

Possible site: Cross-over for canyon river in Colorado



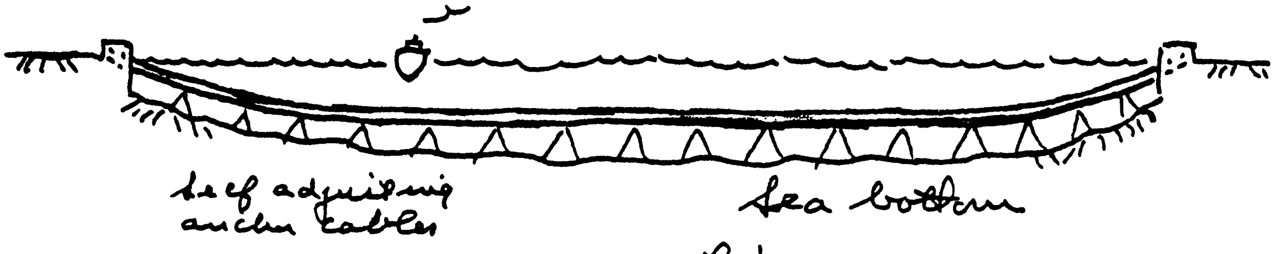
Existing old metal truss highway bridge



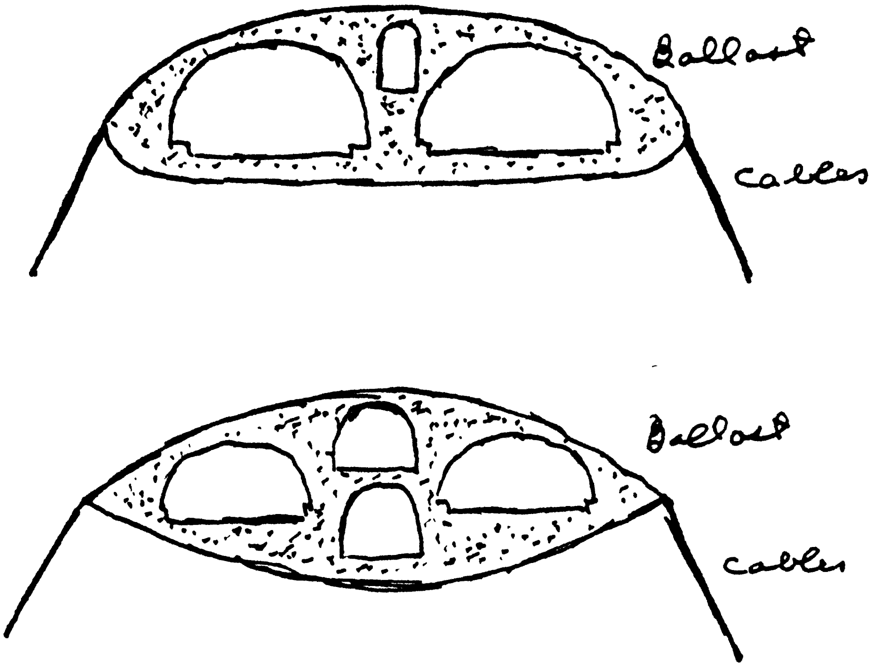
Enclosed for non-vehicular use, such as for a restaurant or an exhibition center. May be at the existing site or at a new location.

Adaptive Use Bridge

Possible site: small town in central Virginia



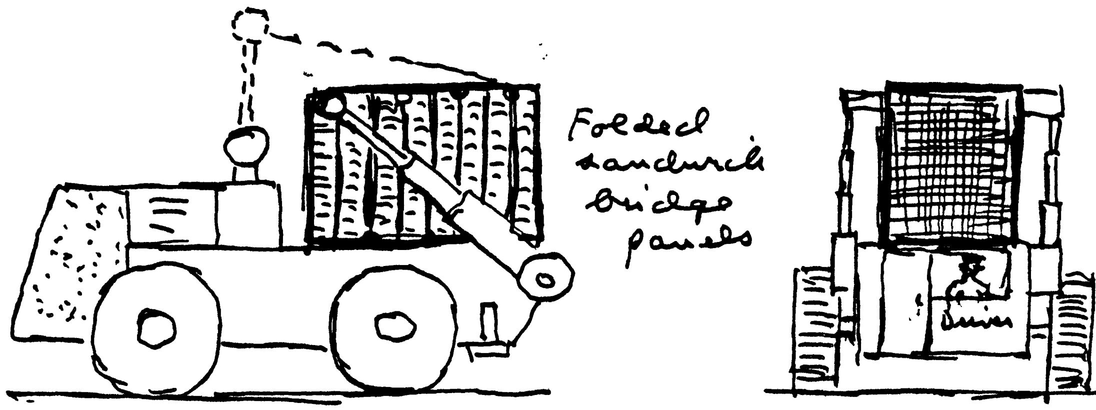
Elevation



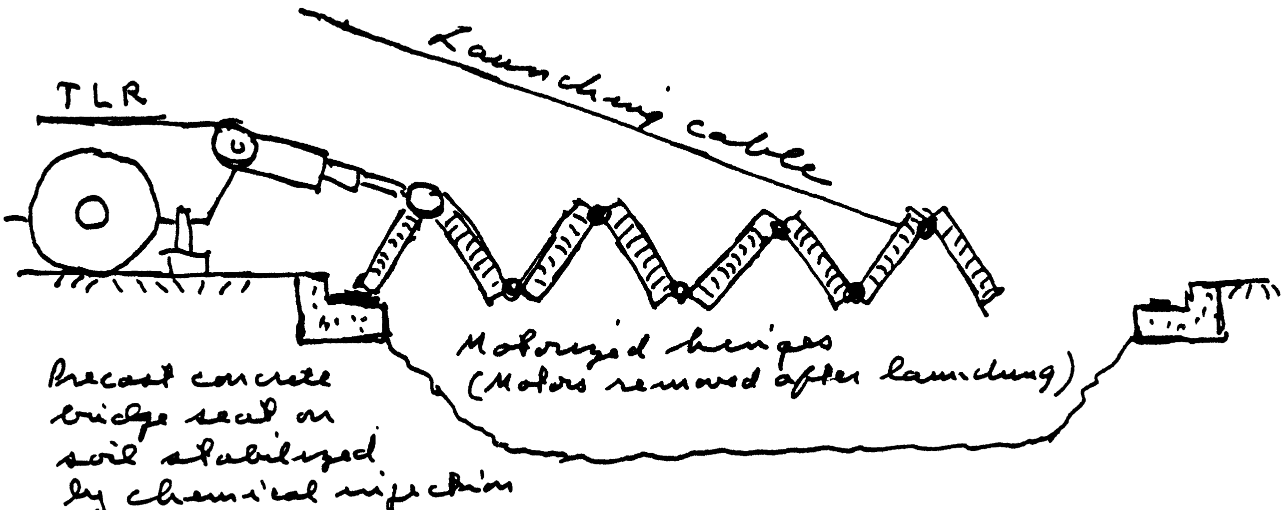
Typical cross-sections

Underwater Bridge

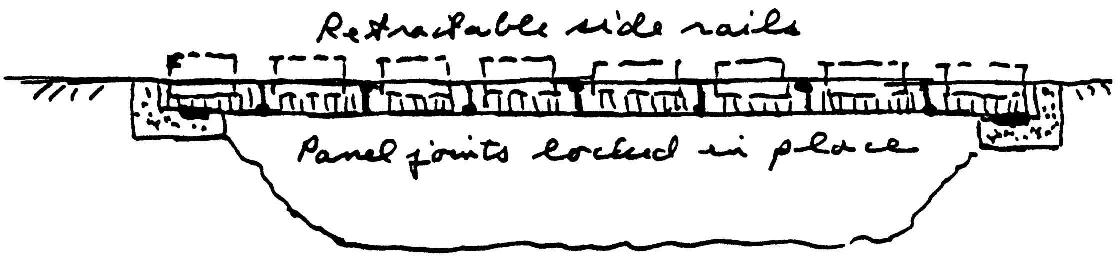
Possible site: Strait of Gibraltar
between Spain and Morocco
Patterned after design by Alan Grant



Transport, Launch & Retrieval Vehicle (TLR)



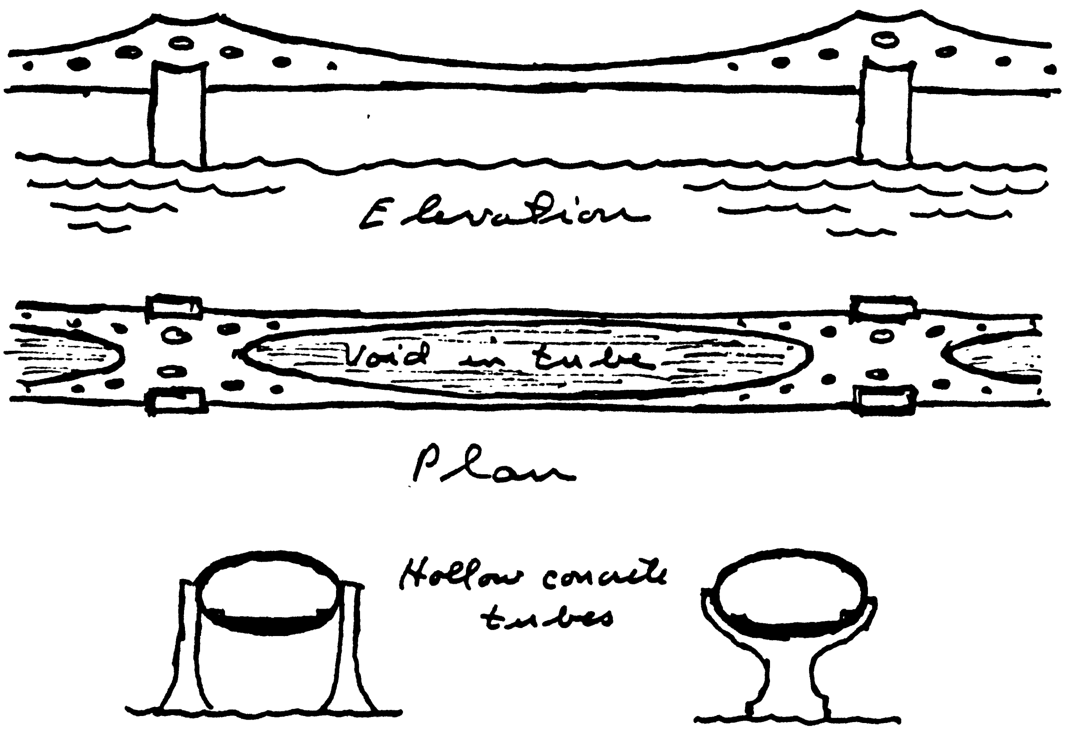
Deployment of bridge



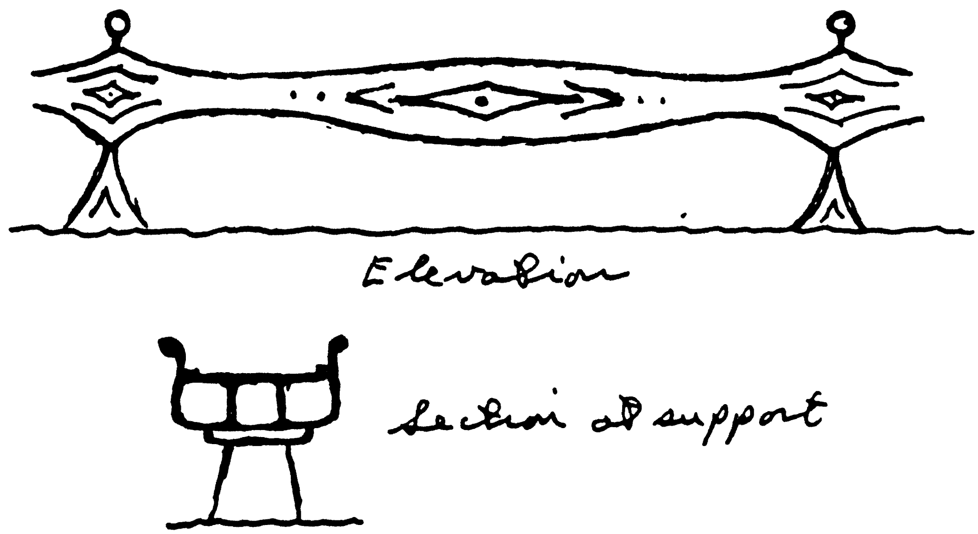
Completed bridge
(May be modified and redeployed at another site)

Kinetic Bridge

Possible site: Wherever a temporary short span bridge is needed

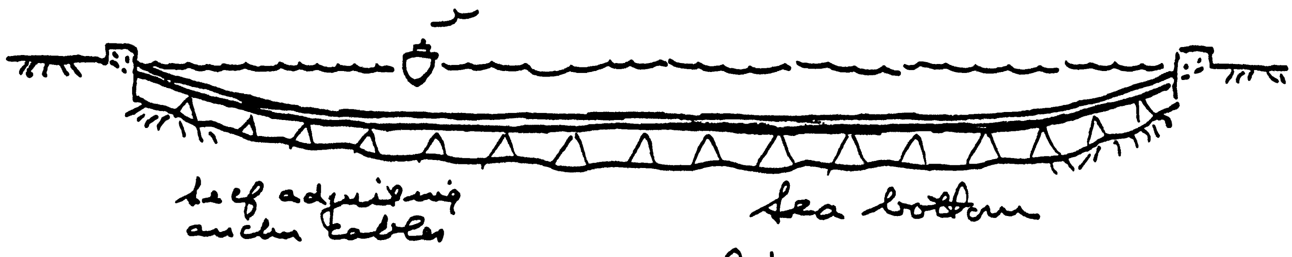


Possible sections at supports

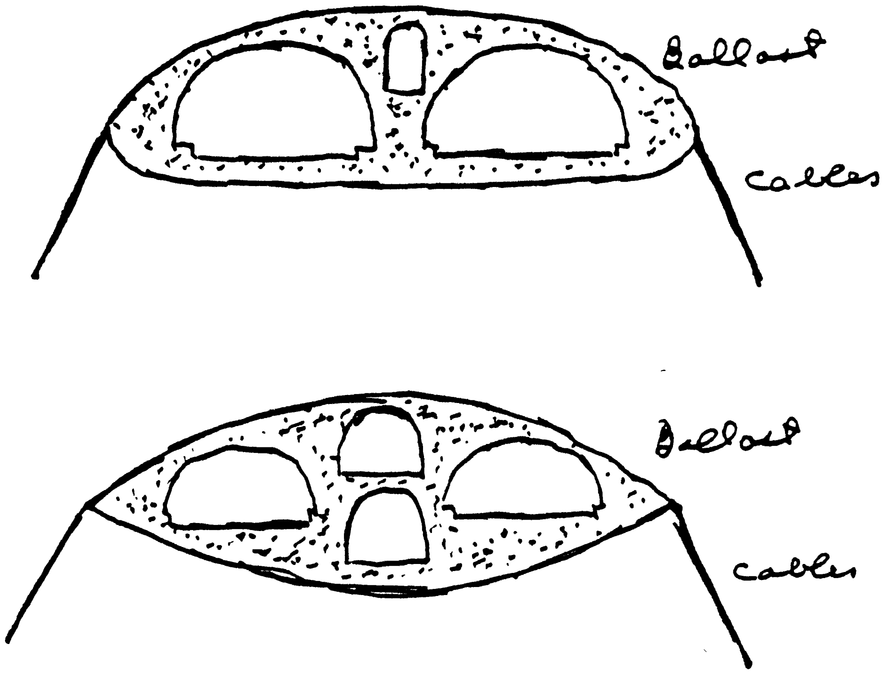


Two High-Style Bridges

Possible site: California



Elevation



Typical cross-sections

Underwater Bridge

Possible site: Strait of Gibraltar
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Patterned after design by Alan Grant