# Stay-cable system for cable-stayed bridges

**F. Graber**

*Cable-stayed bridges offer several advantages, and their number has increased dramatically during the last decade. The author of this paper deals with the VSL stay-cable system and highlights its properties and economics.*

Cable-stayed bridges have extensively gained in popularity for long-span bridges all over the world. A large number have already been built and are demonstrating an excellent in-service behaviour. A number of bridge projects with very long cable-stayed spans are on the drawing-board of reputable design engineers.

The main reason is that cablestayed structures enable bridge builders to create long spans in an economical manner and in building bridges, which harmonize very favourably with the environment and give architectural attraction.

VSL International Ltd, Berne, Switzerland, has adapted its well-known post-tensioning system for the following specific requirements such staycables demand:

1. high fatigue strength
2. adjustability and replaceability
3. good corrosion-protection
4. economic installation and stressing procedures
5. excellent durability.

VSL stay-cables have been successfully used for several projects, such as the Sunshine Skyway Bridge in Florida, USA, Figure 1. Presently, some five projects to be provided with VSL staycables are under construction in various parts of the world.

## Details of VSL stay-cables

The main characteristic of VSL staycable is the use of 7-wire strands for the tensile members. Strands have a high breaking strength which results in a reduced consumption of steel, and a smaller weight of the stays in comparison with other types of tensile members (wire, bar and rope). The high modulus of elasticity provides the stays with a high stiffness and, thus, leads to relatively small elongations under live load. Figures 2 and 3 show the details of the stressing anchorage and components of the VSL stay-cable.

The VSL stay-cable consists of:

1. A bundle of parallel, 7-wire strands of 15mm nominal diameter of stress-relieved and low-relaxation quality. Depending on the crosssectional area the breaking load may range between 246kN to 265kN per strand. For additional corrosion-protection, the strands may be galvanized or may individually be greased and sheathed with polyethylene. The fatigue resistance of the strands at 2 million load cycles and an upper load level of 50 percent GUTS must be 50 percent higher than the fatigue requirements of the stay-cable itself.

2. A stay-pipe encasing the strand bundle, either in high-density polyethylene (HDPE) with carbon black to provide resistance against ulraviolet degradation or steel materials and ratio of diameter-to-wall thickness in accordance with relevant Standards. HDPE pipes have a very high water-vapour diffusion resistance, and the permeability of gases and liquids is very small.

3. An anchorage assembly at each end of the stay-cable, consisting essentially of bearing plate and guide-pipe, anchor head, wedges, transition pipe, tension ring, jointpipe to stay-pipe, and grout cap. The anchor head of the stressing anchorage is generally provided with a thread and a ring nut which allow adjustment of the force or total detensioning of the staycable, whenever required.

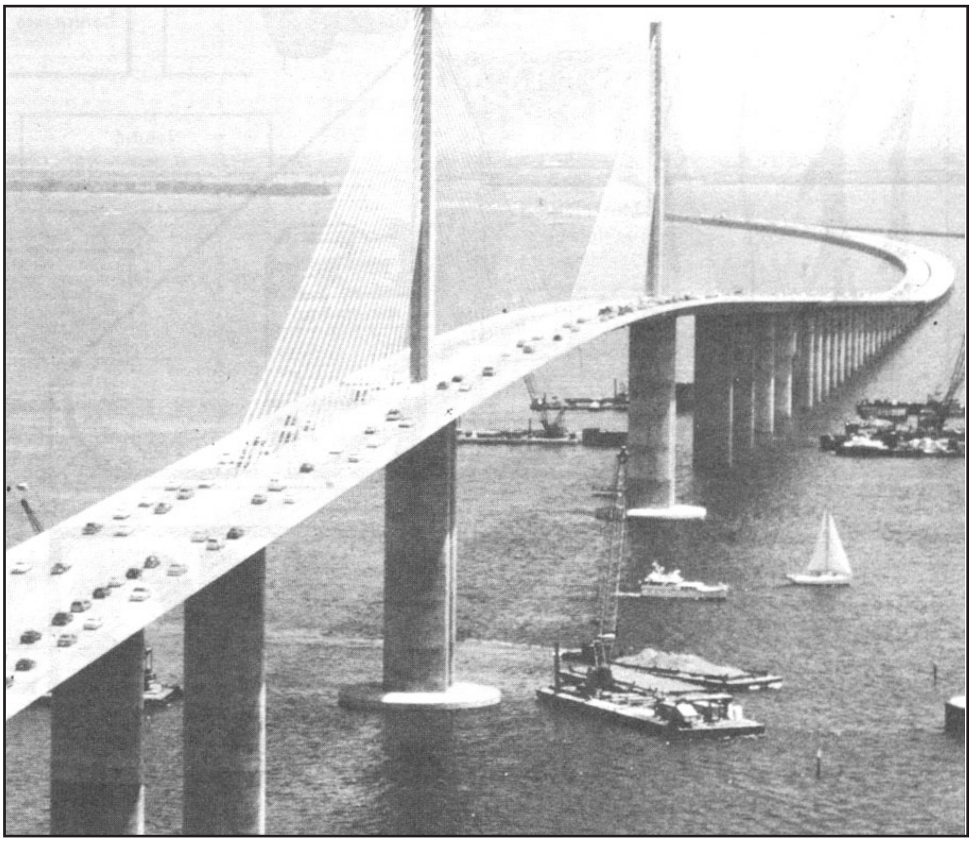

**Figure 1. A panoramic view of the Sunshine Skyway Bridge, Florida, USA**

components and materials used for the VSL stay-cable system in order to meet the required resistance to fatigue.

The technical specifications of almost all stay-cable projects call for full-scale fatigue and static tests to be performed with specimens incorporating the very same design features and materials as the ones to be installed in the actual stay-cables. The fatigue test is generally followed by an ultimate tensile test.

Other tests such as flexural - fatigue tests, e.g., to check conditions in a saddle anchorage in the pylon, may also be specified. In all cases, the acceptance criteria should be set either by national standards or specified by the designer (stress range, upper stress level, frequency, acceptable wire ruptures, minimum force for ultimate tensile test, etc.).

Shims can be installed between anchor head and bearing plate to increase the range of adjustability. A neoprene ring placed at the end of the guide-pipe is centering the staycable and partly absorbs lateral vibrations caused by wind load. A rubber boot provides a smooth and watertight transition from the staypipe to the guide-pipe. The largest standard VSL stay anchorage can anchor up to 91 strands, representing a maximum breaking load of 24,000 kN. The VSL stay-cable anchorages are designed for a fatigue resistance of 200N/mm$^2$ at 2 million load cycles and an upper load level of 50 percent GUTS. This fatigue strength provides a large safety margin over the stress ranges which actually occur in a cablestayed structure.

4. Cement grout around the strand bundle as an additional corrosion protection inside the stay-pipe. The cement grout completely fills the interstices between strand bundle and the stay-pipe. With its alkaline properties it is an active corrosion protection. Other corrosion inhibitors such as petroleum jelly, grease, dry air, etc., are also possible.

When greased and plasticsheathed strands are used, the anchorage zone is filled with a corrosion- inhibiting grease.

## Tests

VSL International Ltd. carried out a number of tests to check and prove the details of the design of the individual

After testing, the test specimens are dismantled and cut for visual inspection to provide information on groutability, lateral pressure on the strands, marks at points of deviation, fretting corrosion, etc.

The testing device for the axial fatigue tests located at the Swiss Federal Material Testing Laboratory EMPA, DObendorf, Switzerland, is shown in Figure 4.

For architectural reasons, designers wish to have very slender pylons. A saddle arrangement for the stay-cables will be an elegant solution in such cases. However, the stay-cable in the saddle will be subjected to high fluctuating bending stresses. To simulate such conditions a test set-up, as shown in Figures 5 and 6, was developed together with Figg & Muller, the designers of the Sunshine Skyway and Neches River Bridges.

The geometry of the test set-up is defined in such a way that the vertical pulsating of the saddle will induce both the required axial fatigue range and the fluctuating bending stress in the extreme fibre of the outermost strand of the cable bundle.

## Working procedures

Due to the simple and clear concept, the VSL stay-cables are most suitable for assembly on site as proved by all major stay-cable projects incorporating VSL stay-cables. Each particular project will call for its own most-suitable method of assembly and installation of the stay-cables, which must economically be

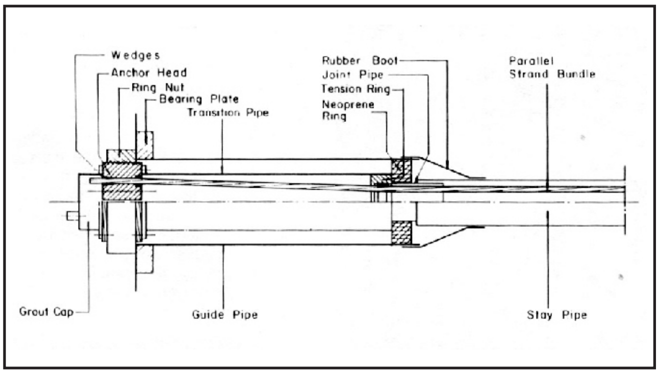


**Figure 2. Details of stressing anchorage and components of the VSL stay-cable**

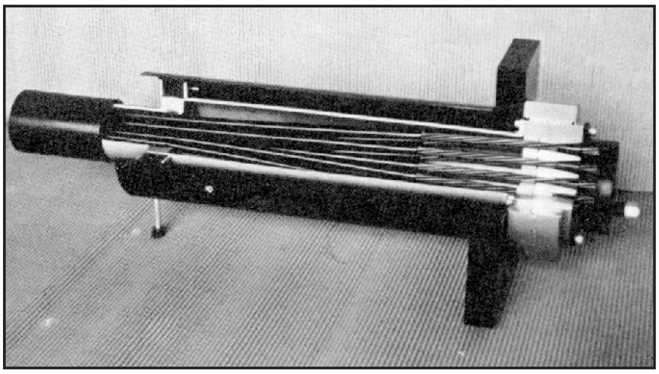

**Figure 3. Open-cut model of a stressing anchorage of the VSL stay-cable**

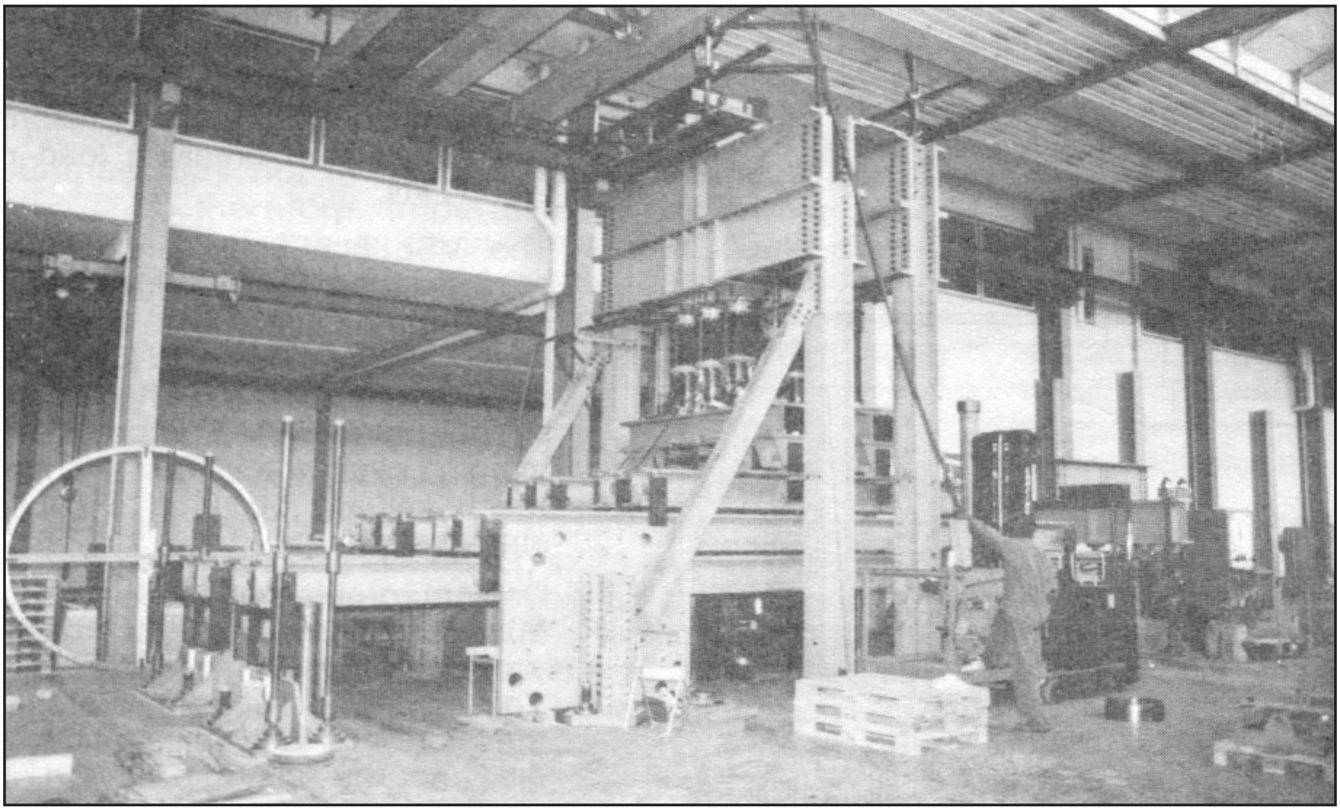

**Figure 4. Testing device for axial fatigue tests at EMPA, Switzerland**

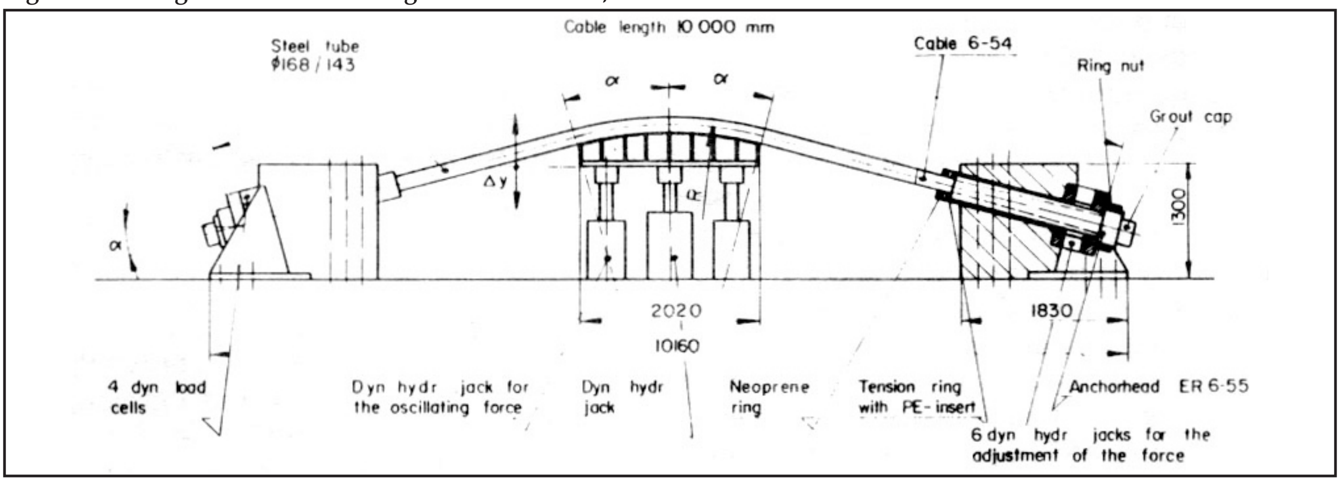


**Figure 5. Test set-up for flexural-fatigue testing**

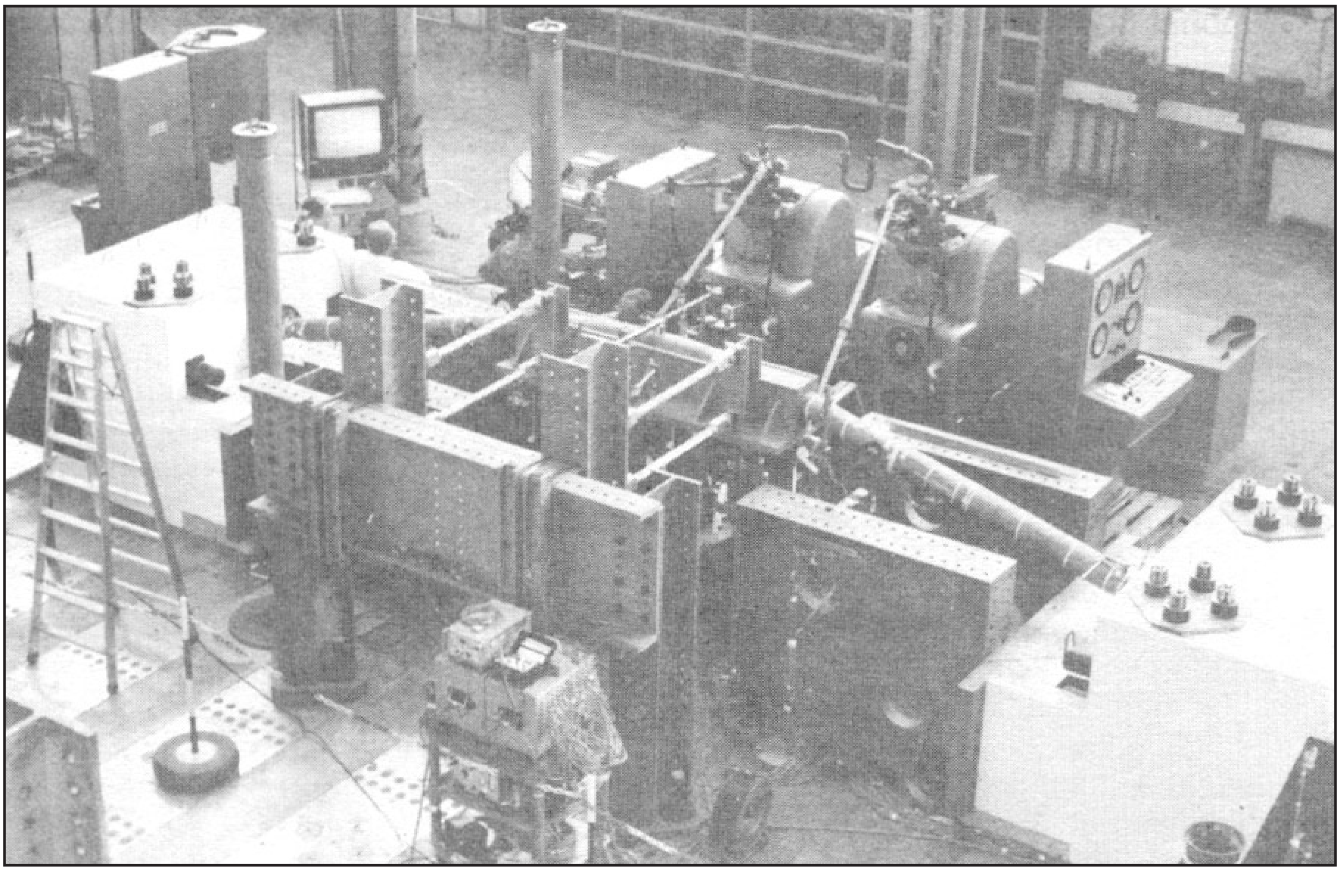

**Figure 6. Flexural-fatigue testing at EMPA, Switzerland**

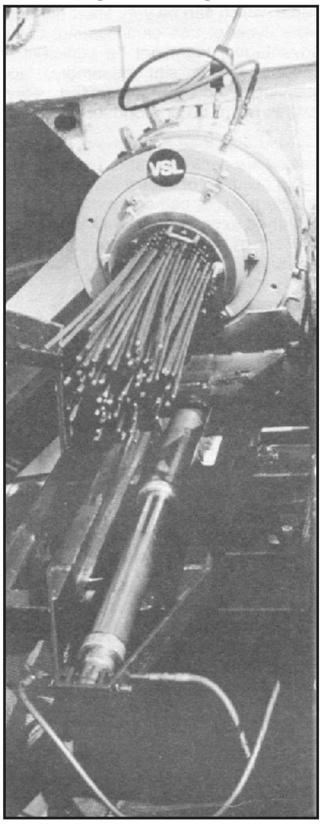

**Figure 7. Stressing of a stay-cable with a VSL centre-hole stressing jack resting on a jack manipulator**

engineered on the basis of parameters dictated primarily by the construction method of the bridge deck.

For stressing, the ordinary VSL post-tensioning stressing equipment incorporating self-gripping assemblies can be used. For load adjustment, special chairs are attached to the jacks. Thus, the simple stressing procedures of the VSL post-tensioning system can also be fully applied when stressing the VSL stay-cables,Figure 7.

The stay-cables are generally fully assembled on the bridge deck and installed by means of cranes, deviation saddles and winches or lifting jacks, Figure 8.

In case steel pipes are used for the stay-pipes, individual production length can be welded in-situ using support frames and mobile cranes. The welded stay-pipe is then progressively pulled up to the pylon by means of a winch while being supported by "bicycles" or steel frames rolling on the stay-pipe underneath, Figure 9. Alternatively, the stay-pipes can be suspended from a messenger cable, Figure 10.

Assembly of stay-cables in their final position, strand-by-strand, by the push-through method from the top anchorage with the stay-pipe being suspended directly by the first strands installed has the following advantages:

1. low investment on installation equipment

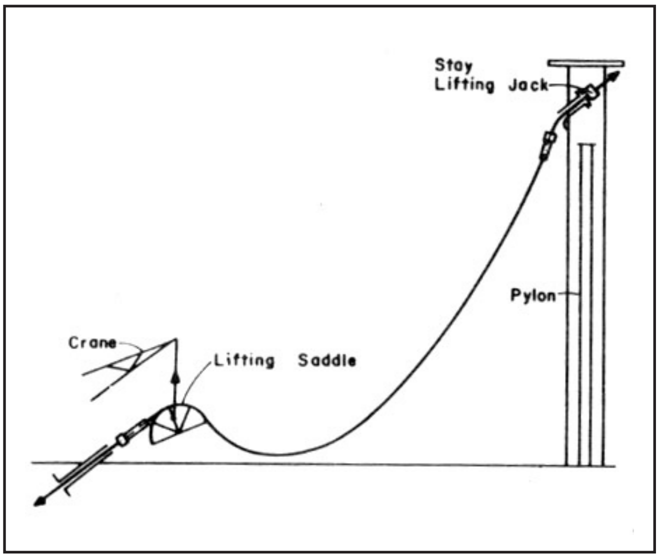


**Figure 8. Installation of assembled stay-cable**

2. moving/lifting of heavy loads can be avoided

3. generally more economical.

However, depending on access to the pylon and/or deck anchorages, height of the pylon and, mainly, time available for installation of the stay- cable, which can be very short during a work cycle of free cantilevering; these advantages might not be sufficient to choose the in-situ assembly, and installation of preassembled stay-cables might be appropriate.

After final load adjustment, the stay-cables are cement-grouted in stages to avoid build-up of excessive hydrostatic pressure. The cement grout used is designed to prevent extensive bleeding caused by the filtering effect of the strands.

## Conclusion

The number of cable-stayed bridges has increased dramatically during the last decade. Due to the many advantages they offer to designers and clients, cable-stayed structures will be an important part of future bridge construction.

The stay-cables are the most important members of this system. They must be safe against fatigue, and be durable and well-protected against corrosion.

The VSL stay-cable system 200 satisfies all these technical requirements. In addition, the VSL stay-cables are economical in price and working procedures.

F. Grater, VSL International Ltd., Konizstrasse 74,
CH-3008 Berne, Switzerland.

(Source: ICJ September 1988, Vol. 62, No. 9, pp. 490-494)

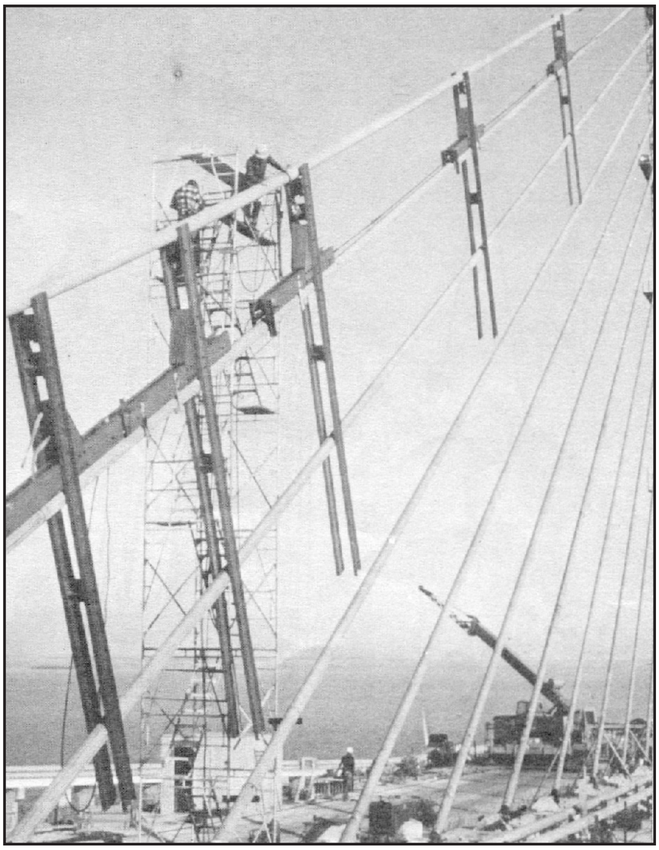

**Figure 9. Installation and welding of stay- pipes in steel and pulling them up to the pylon on "bicycles" at Sunshine Skyway Bridge, USA**

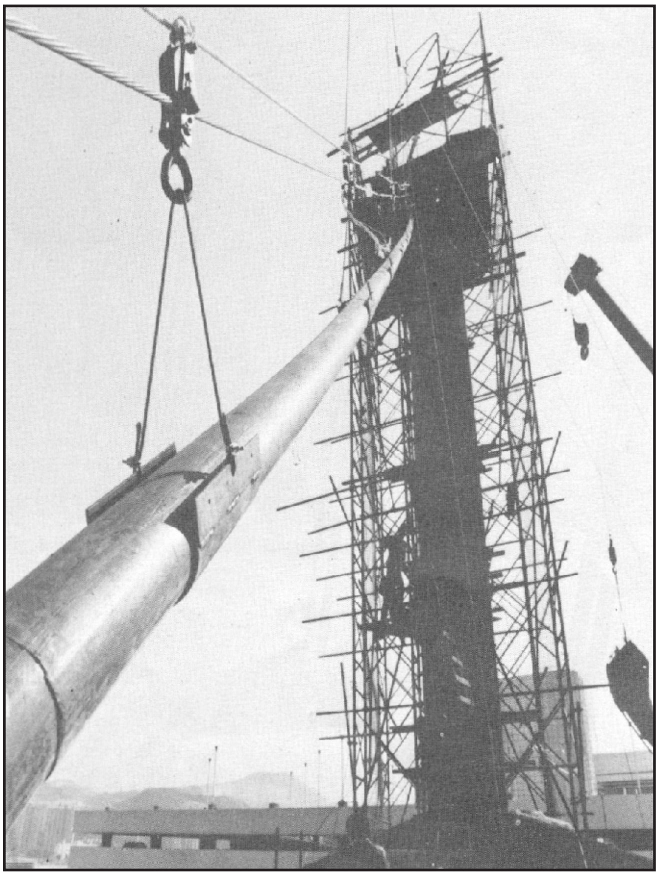

**Figure 10. Installation of stay-pipe, suspended on a messenger cable**