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AN ADVANCED CONCEPT IN THE DESIGN OF LARGE UNORTHODOX STRUCTURES

by

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ABSTRACT

AN ADVANCED CONCEPT IN THE DESIGN OF LARGE UNORTHODOX STRUCTURES

During the early years of design and construction of the large, complex facilities and structures at the Kennedy Space Center in Florida, it became apparent that conventional structural practice utilizing generous safety factors would be unacceptable. Therefore a small group of civil servants in the NASA Design Engineering Directorate developed a new and advanced concept for building these structures and facilities.

Mr.George Walter (Deceased) led the investigation which resulted in the approach that will be discussed at length in the paper. It is interesting to note the rigorous interaction that occurred with the Civil Engineering Society and those responsible for the body of structural codes.

1. INTRODUCTION

In discussions with the Florida Department of Transportation, it became apparent that the problem of design of movable bridges is similar to the problems faced by NASA Kennedy Space Center in designing free-standing towers for the Apollo launch facilities. In both cases it is important to realize that we are dealing with a dynamic structure rather than a static structure. Not only do operational considerations drive such a design but also we must consider more than the natural environmental factors. In KSC's case the acoustical vibration and launch related pressures coupled with a severe salt fog environment and potential hurricane forces dictated the design options. This paper discusses some of the design considerations employed by NASA in the design of the Mobile Launch Umbilical Tower for Complex 39 with the hope that some technology transfer will aid bridge designers.

2.0 GENERAL

The frequent reevaluation and changes in the structures associated with KSC facilities and equipment emphasized the need for complete, detailed design drawings and specifications supported by lucid, well organized calculations. We learned that statically determined framing, wherever possible, simplifies re analysis and redesign. These non conventional facilities are program oriented or experimental in nature. These structures are characterized by unusual or inadequately defined loading conditions, a lack of established design precedent, or frequent modifications to support changes in operational procedure. The KSC-STD-Z-0004 is considered to be the standard developed to direct structural design efforts in to channels which facilitated the response to operational needs and set forth other structural design requisites which have proven to be particularly suitable at KSC.

We used in our calculations dynamic wind loads as illustrated in Table 1 which lists steady state and peak design pressures. The magnitude of the pulse is the summation of each element of peak pressure less its corresponding steady state pressure acting on the windward projection. The periods between adjacent pulses vary but over a minute or two the average time between pulses can be assumed as constant with little effect on the final design.

Hurricane Design Pressure
(pounds per square foot)

Feet Above Ground Level	Peak Wind Velocity MPH	Steady State Pressure	Peak Pressure
30	125	30.8	52.0
60	138	39.5	63.3
100	148	47.5	72.8
200	164	61.6	89.4

Table 1

3.0 TOWER DESIGN CONSIDERATIONS

The Mobile Launcher Umbilical Tower was the designed in 1963 by Dr.L.E Grinter assisted by Dr.Don Sawyer under contract to Reynolds, Smith and Hills. The post design studies were by Dr.L.H.Cox. The towers were free-standing and more slender than used in general practice. Therefore we were concerned about the Natural Period. The slenderness ratios (height to least side of base) of these towers vary from 6 to 1 to 9 to 1. The natural periods of the towers fundamental bending mode have varied between 1.66 and 1.25 seconds per cycle.

Since the structural frames must be designed before many of the final operational requirements have been developed, it is useful to follow the following design sequence.

There should be a preliminary dynamic analysis performed. We recommend a computer program be established to study the dynamic effects of the wind pulses on the structure. The pulse should be assumed as acting on the windward and leeward faces simultaneously. This is conservative because depending on the distance between two faces, the positive pressure would usually be out of phase with the suction on the leeward side and would tend to reduce oscillation in a tower. The natural period of the first bending mode should be established for the tower in as many vertical bending planes as required to establish a full array of representative samples. It should be understood that we have taken the position that the more probable destructive effect of a hurricane is that of large wind pulses that vary considerably in frequency but which seem naturally to occur with an average frequency within the possible resonance limits of a tower structure. We further recommend sufficient computer runs for each representative bending plane, over an array of average gust period (none to be less than 1.66 seconds) to determine which combinations stabilize and how many seconds it takes for the combination to stabilize or reach a maximum. These data should be arranged in the form of a matrix. A final dynamic check should be made including:

(a) Spring constants at tower leg reactions.

(b) Strengthening of diagonals to transfer the shear of the accelerating mass above them as the tower oscillates.

(c) Check of records for local wind conditions.

One of the significant details is the design of energy absorption joints so that the proper orientation of the web member connections in the plane of each tower face permits the high strength bolts be in shear if the friction joints of the member connections were to slip. As a special precaution against tower failure under extreme oscillations, the slipping of the faying surfaces, with respect to one another, while still clamped by the bolts, would be a most effective dampener. We sized the bolt holes of the inner clamped members to be 3/16 inch oversize instead of the usual 1/16 inch.

4.0 <u>OTHER DESIGN CONSIDERATIONS</u>

A topic which will be developed in both this paper and the presentation is safety factors. The term "factor of safety" is used as a measure of structural integrity but its precise definition varies with the degree of uncertainty and who does the defining. Most agree that design safety factors based on yield strength should take into account the ultimate strength characteristics of the components. But it must also be a function of how confident the designer is in selecting design loads that represent the actual service loads both <u>both present and future.</u> In using the term "factor of safety, the least ratio of capability to requirements should be the implied criterion. Whereas tension, compression, or bending stress may be the usual basis for the expressed factor of safety, we recommend the designer verify that no other stresses or conditions give a smaller ratio. Other stress and conditions include shear, torsion, bearing, Hertzian stresses, combined stresses, buckling, fatigue, creep, corrosion and wear. Loads which have been increased by arbitrary load factors <u>should not be used</u> in calculating stresses for use in determining factors of safety. Only combinations of static and the static equivalent of dynamic loads should be used.

To ensure that the safety factors are meaningfui, we direct your attention to connections and fittings. We feel that special care shall be taken to ensure that the connections or fittings joining the parts are designed to represent the actual end conditions of these parts. Factors of safety should be increased to reflect the stress concentrations that are inherent in such connections. The end connection should be designed to develop the full allowable strength of the connected part rather than its required calculated strength. The intent is to maintain consistency in the factors of safety for the connected part and its connections and to simplify the inevitable future modifications.

5.0 OBSERVATIONS

While the previous discussions draw heavily on the NASA KSC Standard it also reflects the experience of successful design and operational structures at the Kennedy Space Center launch pads. It becomes the moment of truth when significant cracks appear in the structure or operational requirements change the existing structure as in the case of the Apollo/Soyez mission which required the fabrication of a "milk stool" to adapt a smaller launch vehicle to the existing umbilical tower. These experience have given us confidence that our approach was successful and could serve as a guide to designers of similar structures. Further, the basic design of a movable bridge structure appear to have similar design characteristics and might benefit from our tower experiences.

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