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Stress Measurements on Blair High School Gymnasium: A Demonstration of Space Technology Transfer

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CONTENTS

FIGURES

ABSTRACT

14630

This Report describes an actual demonstration of transfer to non-space use of technologies developed for space programs applications. Techniques used in assessing static and dynamic characteristics of the Blair High School gymnasium involved data acquisition by continuous scanning of strain gauge data acquired over a time of wide-temperature range, and analysis by a computer routine developed by Jet Propulsion Laboratory five years ago. The advantage of this method over conventional structural testing of uniquely designed structures was proved. More importantly, the process of demonstration was shown to be of great assistance to, and extension of, normal methods of disseminating information of new technologies. It is felt that significant benefit will derive from this improved mode of concept transfer.

Author

I. INTRODUCTION

Since the advent of the space age, many farsighted individuals readily discerned benefits that could accrue to non-space areas of our society. These benefits are now coming to be realized in the public sector, chiefly as a result of the efforts of the National Aeronautics and Space Administration (NASA) Office of Technology Utilization. Through the information-distributing systems administered by this Office, knowledge of space-related developments that have other feasible applications is being imparted in ever increasing circles to members of non-space industrial and research organizations.

The Jet Propulsion Laboratory (JPL), as a NASA contractor, has been responsible for many space developments, a number of which could be employed profitably in other ways, as well. The Blair High School project, which is the subject of this Report, is an example of one such transfer of new technology. The unique aspect of the technology utilization in the Blair project was the actual demonstration of methods and techniques, which clearly illustrated to the participating parties the relative advantages of this new concept to current, accepted techniques.

The project has been a cooperative venture, involving not only Jet Propulsion Laboratory but, also, the California Institute of Technology (CIT), the Pasadena Board of Education, the architectural firm of Neptune & Thomas Associates, the California State Division of Architecture, Western Iron and Metal Company, and S. Patti Construction Company. Dr. Robert D. Hanson of CIT directed the field test work and Mr. Paul H. Winter of Neptune & Thomas Associates supervised the overall program.

Specifically, the project concerns the transfer into the structural engineering field of an instrumentation concept or technique that was initially developed for structural static testing of space vehicles. Documented here is the use of this system in conducting a stress analysis of the structural frame of the Blair High School gymnasium.

The concept for this particular project originated with Professor Donald Hudson, Mechanical Engineering Department, California Institute of Technology. For some time, Professor Hudson has explored the possibilities of utilizing space technology in the field of earthquake engineering; he has succeeded in defining several ways in which instrumentation and data processing techniques that were developed for space research could be of invaluable aid in structural engineering.

The first of these proposals dealt with the utilization of the *Ranger* lunar seismometer to determine the dynamic characteristics of large constructions, such as buildings and dams, and their likely responses to earthquakes. Indeed, Professor Hudson and others have already used a demonstration model of that seismometer to perform such tests and analyses (Ref. 1).

Hudson's second recommendation for this kind of application was to use a digital data acquisition and analysis system for static structural testing. It was this idea that formed the technical basis for the cooperative effort on the Blair High School gymnasium. Out of a common purpose and interest, then, it was proposed that the Jet Propulsion Laboratory assist the California Institute of Technology in performing a stress analysis of the Blair High School gymnasium now under construction in the City of Pasadena.

II. DESCRIPTION OF THE PROJECT

A. Purpose

The purpose of this test was to assess: (1) the static characteristics of the structural frame by quantitatively and qualitatively determining the response of the structure to such steady loading factors as its own weight; and (2) the dynamic characteristics of the structure, or the likely response and resistance of the building to earthquake. The dynamic measurements were made solely by technical representatives from CIT.[1]

After careful consideration of the test parameters and goals, the responsibilities of the groups participating in the test were defined. It was agreed that the Jet Propulsion Laboratory would furnish the instrumentation equipment required for the digitalized data processing technique, together with the technical assistance to operate this equipment during the actual test. Equipment from the Laboratory included: a 50-channel data acquisition system and commutator, an analog-to-digital converter, an analog strip recorder, a digital lamp-bank display, and a paper-tape punch.

The most significant contribution made by JPL, however, was the static structural-testing technique, itself, that was originally developed at the Laboratory for measuring the structural integrity of spacecraft. Essentially, this technique is one of data processing and analysis. Data acquired during the test are processed to digital form, recorded and analyzed by an existing computer routine that was prepared at JPL about five years ago.[2] The Laboratory's portion of the project was completed when the results of the computer routine were supplied to CIT for final analysis and incorporation in a technical report to be published by the Institute.

Dr. Robert Hanson, in addition to supervising the field test work at the site, will be responsible for analyzing both the static and dynamic results of the test program. Out of his work will come a thorough technical publication that will describe in detail the technical aspects of the project and will contain a statement on the structural integrity of the building, resulting from his analyses.

B. Comparison of Conventional and New Technologies

It is the instrumentation concept, itself, that is of primary importance in the potential technology transfer;

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[1] Both the dynamic and static test analyses will be included in a report published by CIT.

[2] Chow, E., "Standard Procedure for Use of Digital Data Acquisition System for Static Structural Testing," Interoffice Memo, Jet Propulsion Laboratory, July 14, 1960.

and, in particular, it is the JPL developed data-processing and -analysis routine that constitutes a significant advancement.

In traditional structural-testing techniques, when strain gauges are employed, a comparatively small number of them are used; they are connected, in groups, to resistance bridges, and potentiometer measurements of the bridges are then used as data. As different characteristics are measured for various static and dynamic modes, it is necessary to rearrange the strain gauges in their circuitry to the resistance bridges; then the data are usually recorded by hand.

In the new technique developed originally for space application, strain gauge data are scanned continuously and are acquired by the multichannel recorder while the structure is being loaded. The analog data acquired are processed to digital form and are encoded onto a punched-paper tape. Next, the taped data are fed into a computer, using a JPL developed computer routine, to make a thorough analysis in a manner not previously employed in architectural design. The computer program developed specifically for this instrumentation system then uses the taped data to match and compare the outputs of the various strain gauge readings. Equivalent or more thorough evaluation is accomplished by the new technique, using one installation of gauges, than can be done by the traditional technique, making repeated changes in connections to the resistance bridges.

A comparison of the two techniques shows there are several clear advantages to this new concept: First, a great saving of time is effected, since there is no necessity for rearranging the hookups to the gauges for each new measurement series; second, much more data for the same expense and effort can be acquired, since the data acquisition system and computer analysis can handle the output of many more gauges. The overall result of these two factors is a much more thorough analysis of the structure in less total time than is required by conventional methods.

There is a third real advantage that, in time, the results of this project should make apparent. Often, for buildings of new and unique design, conventional structural-stress calculations are done in lieu of structural tests. Because of the difficulty in computing stress requirements for such structures, excessive safety factors frequently are used. As a consequence, wasteful, excessive material and labor are used to meet the too highly calculated stress requirements. Use of the new testing technique could increase the certainty of structural integrity measurably for all kinds of structures; at the same time, it would eliminate unnecessary expense incurred in building to meet the too highly estimated requirements.

C. *Description of the Test Structure*

The Blair High School gymnasium has some unique and distinctive features of architectural design (Fig. 1).

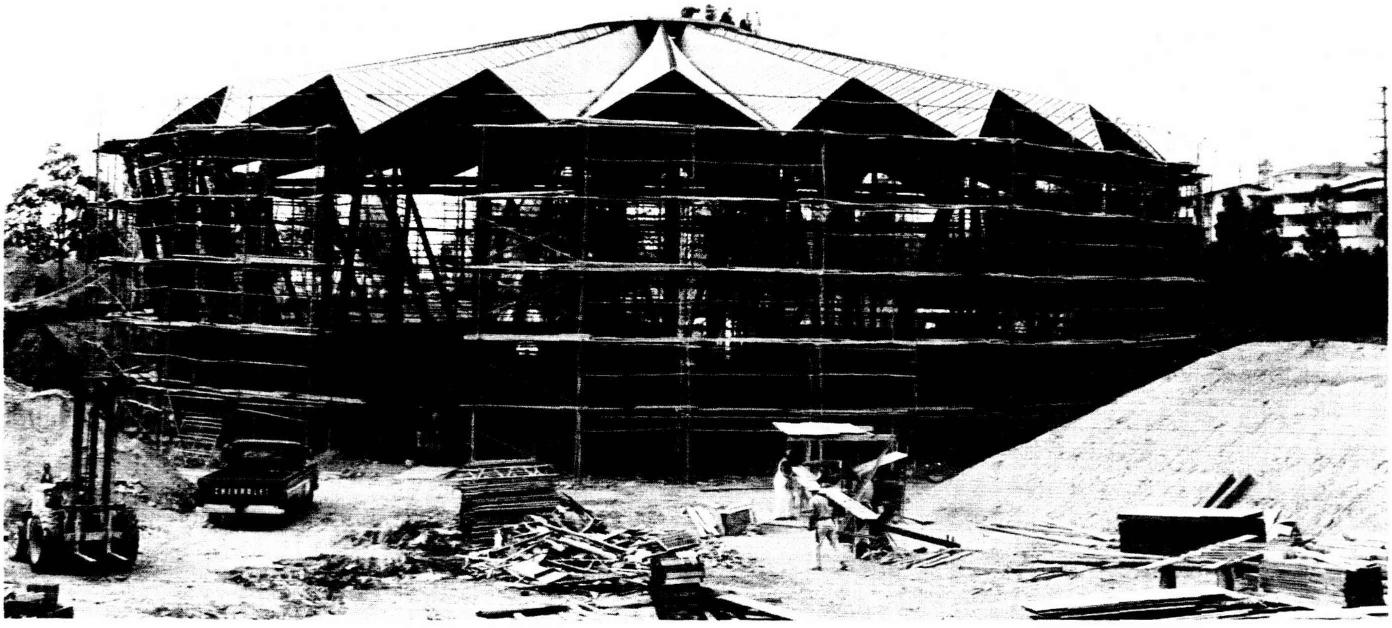


Fig. 1. Blair High School gymnasium:view parallel to major axis

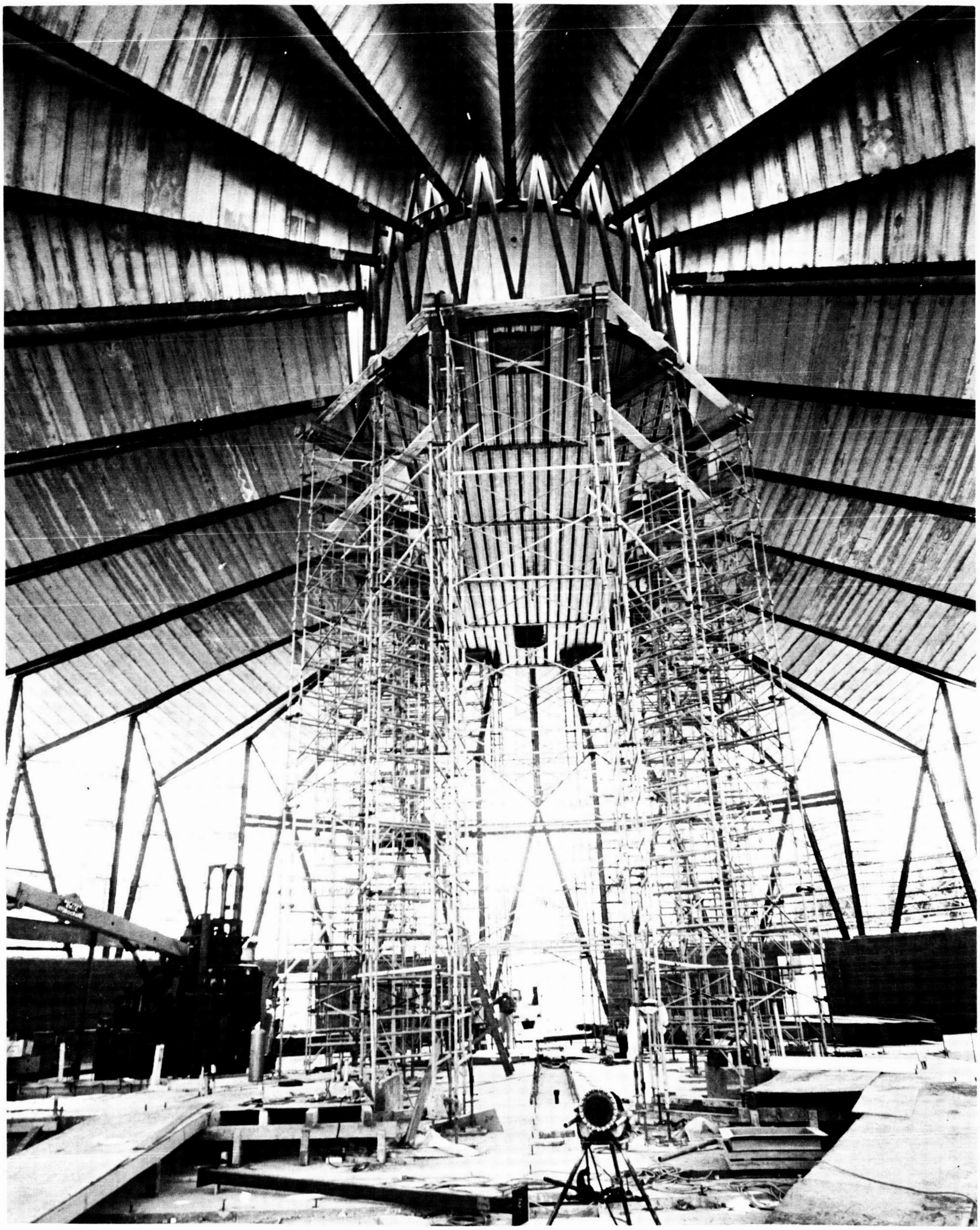


Fig. 2. Interior view showing jack array

Fig. 3. Facility equipment platform supported by jack array

The structural frame of the oval-shaped building rests on a concrete slab, which is surrounded by a peripheral concrete-block wall some 10-ft high. This supporting structural framework is made up of both V-shaped and vertical beams which are welded to the roof along members of the structure that resemble fold-lines in the roof section. The cuneiform shapes of the roof segments radiate outward and downward from a flat oval center section, which is the highest point of the building.

Beneath this center oval section, a platform has been suspended on which will be installed the building's heating, air-conditioning and electrical facilities (Figs. 2 and 3). In order to minimize the structural loading on the building during construction, an array of scaffolding jacks has been positioned beneath this platform to support the roof section and to prevent this load from being impressed on the roof beams and space frame. During testing, these jacks are gradually lowered to the point where they no longer support the platform; at this time, the structure is fully loaded, and maximum stress is realized.

D. Locating Strain Gauges

An initial survey of the structure was made by technical representatives of the cooperating members to determine the locations of the points on the structure where measurements were to be obtained. These specialists agreed that maximum stress would be imposed in the structure along the major and minor axes of the building (Figs. 4 and 5). As the jacks are lowered, the stress loading is increased through the roof beam members to the vertical support beams and a compressional mode is impressed at those points where the roof members impinge on the vertical space frame. Within these areas, 44 strain gauge locations were selected to measure the maximum stress as the structure was gradually loaded (Figs. 6 through 9).

After consideration of such parameters as maximum stress, temperature, and structural material, strain gauges (Fig. 10) that would give optimum results were selected and procured. Shortly thereafter, the components of the data acquisition system were readied and installed in a trailer and, together with a portable gasoline engine power supply (Fig. 11), were sent to the building site.

Strain gauges were then installed at their pre-selected locations and cabled into the data acquisition equipment housed in the trailer (Fig. 12).

E. Test Procedure

Prior to the test, the entire system circuitry was checked to ensure that all instrumentation and equipment was operating properly. Immediately thereafter, the 44 channels for data recording were calibrated to complete the test equipment preparation.

Two major phases to the static structural testing of the gymnasium were performed. The first phase involved measuring all stress parameters at short time intervals while the supporting structure was being loaded. Initially, 44 channels of data were recorded every 5 min while the jacks were being lowered. However, since the

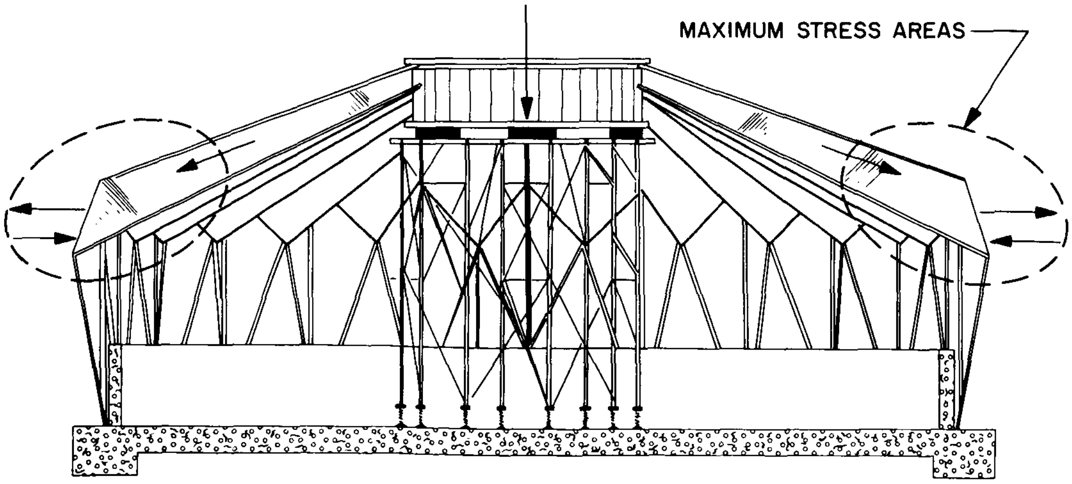


Fig. 4. Front elevation of gymnasium structure

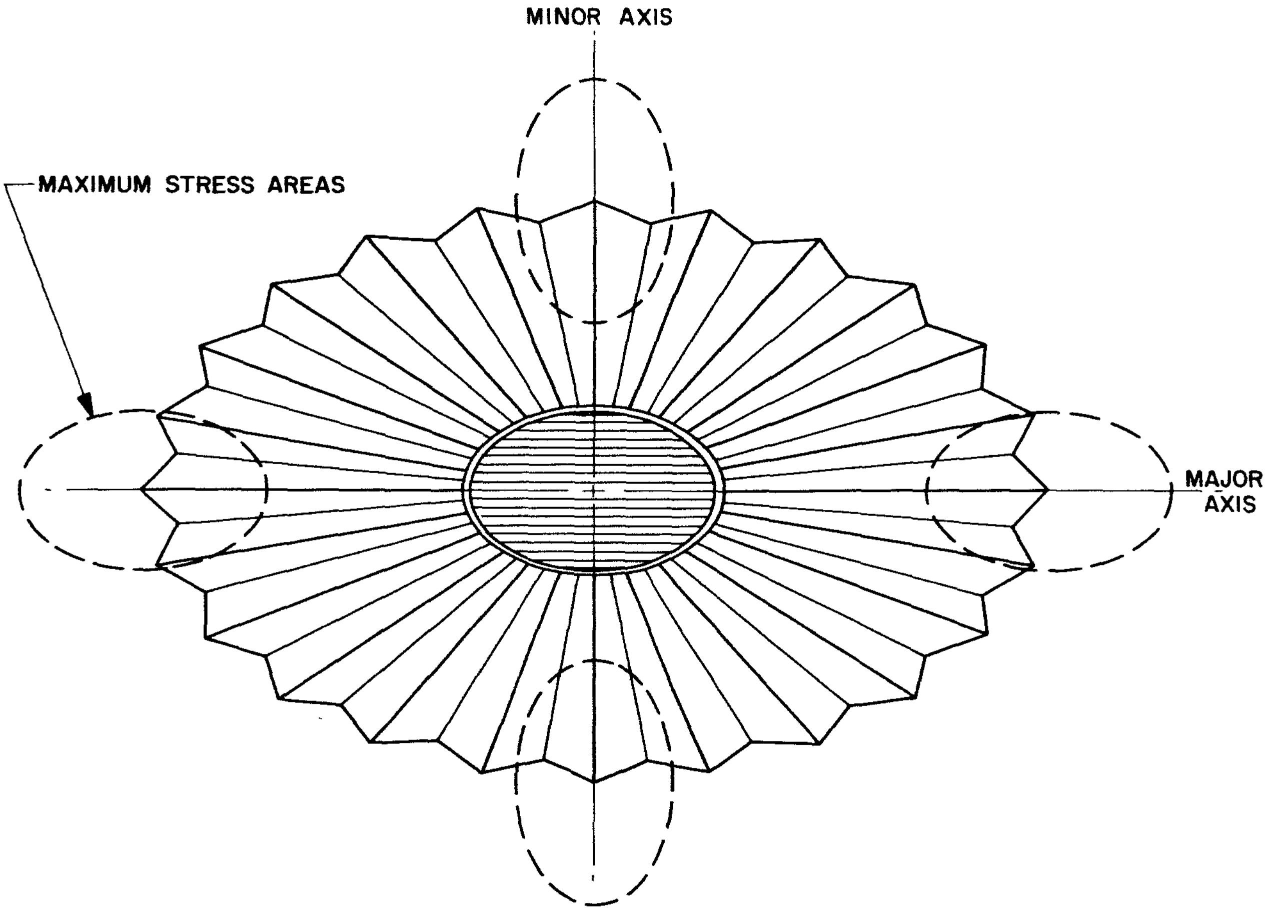


Fig. 5. Plan view showing major areas of stress

stress increase proved to be too small to merit data acquisition at 5-min intervals, the time intervals were lengthened to 15 min. Approximately 1 hr after the test had begun, the platform was freely suspended, and maximum stress on the space frame and roof members was realized.

The platform was left in free suspension for the second phase of the static test program, which specified measuring the variation of maximum stress caused by environmental-temperature change over a diurnal cycle. In order to achieve as wide a range of temperature difference as possible, it was necessary to wait several days for the optimum weather conditions—a clear, hot day and a cool evening. When these conditions and temperatures were forecast, the temperature-stress measurements of the static test began at eight o'clock in the morning. Recordings were made on all 44 channels at short time intervals throughout the day and night and until noon the following day.

When the two test phases were completed, the data, which were already digitized and encoded onto the punched paper tape, were sent to JPL for computer analysis. Subsequently, the computer results were verified and given to Dr. Robert Hanson at CIT for final analysis and incorporation in his technical report on the subject.

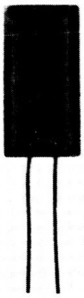
Fig. 6. Strain gauge installation on V-shaped support beam

Fig. 7. Strain gauge installation on roof fold-line member

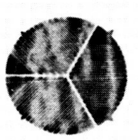
Fig. 8. Strain gauge installation on roof edge on mirror axis of structure

Fig. 9. Strain gauge installation on roof fold-line member along minor axis

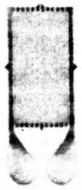
FABW-25-12S-6
LOT NUMBER: 523-AT
GAGE FACTOR: 1.90 ± 2%
GAGE RESISTANCE (UNMOUNTED): 121.5 ± 0.5 ohms



FAR-50-12-45S-6
LOT NUMBER: 243-2
GAGE FACTOR: 2.09 ± 1%
GAGE RESISTANCE (UNMOUNTED): 120 ± 0.5 ohms



FA-50-12S-6
LOT NUMBER: 528-1-BF
GAGE FACTOR: 2.07 ± 1%
GAGE RESISTANCE (UNMOUNTED): 120 ± 0.2 ohms



C6-121-R3A
LOT NUMBER: A3-E-14
GAGE FACTOR: SIDE GAGES: 1.98 ± 1/2%
CENTER GAGE: 2.00 ± 1/2%
GAGE RESISTANCE (UNMOUNTED): 120 ± 0.2 ohms

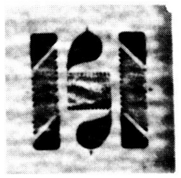


Fig. 10. Typical strain gauges

Fig. 11. JPL instrumentation trailer, with portable power supply and air conditioning units, at construction site

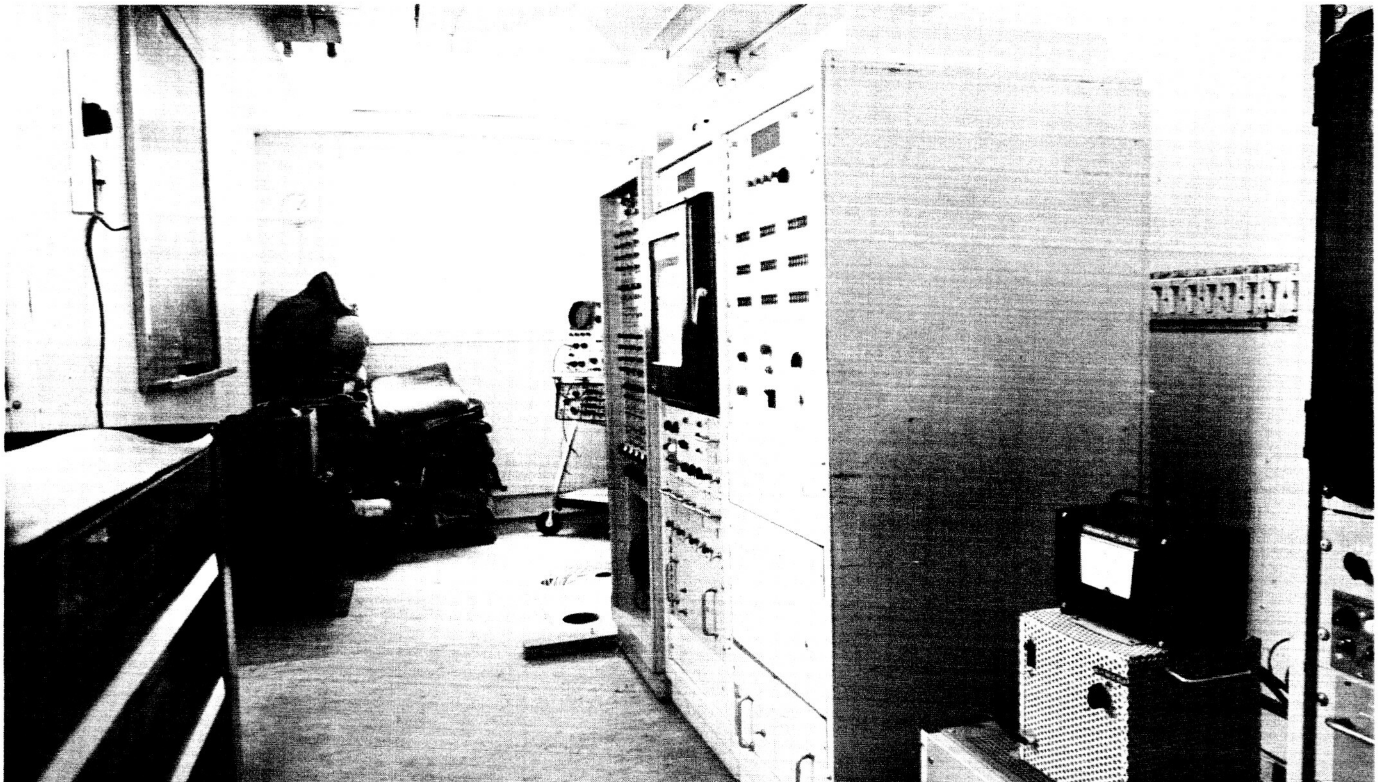


Fig. 12. Data acquisition equipment in JPL instrumentation trailer

III. IMPORTANT BENEFITS FROM THE PROJECT

A. Immediate Benefits

There are a number of benefits, both immediate and far-reaching, that define the importance of the Blair High School project. The advantages of this instrumentation concept clearly dictate that its use be recommended over conventional structural testing techniques. As has been pointed out, this technique produces more data in far less time than do traditional testing methods. This fact, in itself, recommends more intensive use of the concept, not only to ensure integrity of unique structural design but, also, to act as the medium whereby, eventually, excessive construction costs can be reduced without jeopardizing safety.

It seems quite apparent, then, that wide dissemination of the results of this demonstration of space-technology transfer should secure significant benefits to various federal, state, and local construction projects, as well as to the technology of structural engineering.

B. Potential Benefits from Concept Transfer by Demonstration

It should be kept in mind that the Blair High School project, in addition to its intrinsic values, also is an example or test case for an additional means of technology utilization—that is, of the use of demonstrations to effect transfer of new technology. In disseminating information on patented items, NASA goes considerably beyond the simple act of recording the patent declarations.

The results of this dissemination policy appear to be fruitful. Additional publication and increased effort to spread information seem to have resulted in technological developments in various non-space activities of a value far outweighing the rather minor expense involved in producing these publications.

The idea in the case of Blair High School is quite analogous; that is, a step was taken beyond the publication or disclosure of the technique, by creating an actual demonstration in the field of the application of this concept to the structural analysis of the school building, then using this demonstration as the basis for descriptive publication. The simple publication of the instrumentation concept would certainly have an effect just as the recording of a patent disclosure would certainly have an effect. However, the report of an actual field demonstration, illustrating the transfer application, can have a much broader impact, as do the flash sheets, technology handbooks, and utilization notes, which NASA currently distributes on its inventions.

Of even perhaps greater importance of the associated values to be derived from the Blair High School project is the fact that a concept was demonstratively transferred into a non-space technology. There are already in existence well developed techniques and systems for the distribution of information on NASA-developed *components* with possible use in non-space fields. It is our opinion that a similarly aggressive policy toward the dissemination of information on NASA-developed *concepts* might have an equal, or perhaps even deeper, effect on non-space activities.

Ironic as it may seem, the development of new components has always been paced by the development of new concepts in the growth of space technology; literally, these tangible items have emerged from pre-existing concepts. Moreover, the task of concept transfer is probably more difficult than new applications of componental hardware. It is our belief, however, supported by the manner in which the Blair High School project was formed and the results obtained, that by the process of demonstration, followed by publication and dissemination of the results of the demonstration, this problem of technology transfer can be solved.

REFERENCE

1. Hudson, D. E., Keightley, W. O., and Nielsen, N. N., "A New Method for the Measurement of the Natural Periods of Buildings," *Bulletin of the Seismological Society of America,* Vol. 54, No. 1, pp. 233-241, February, 1964.