NATIONAL BUREAU OF STANDARDS REPORT

7387

Test of the Mobilization Structure
Under Sustained Uniformly Distributed Load

by

L. F. Skoda

Report to

Bureau of Yards and Docks
Department of the Navy

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

Functions and Activities

The functions of the National Bureau of Standards are set forth in the Act of Congress, March 3, 1901, as amended by Congress in Public Law 619, 1950. These include the development and maintenance of the national standards of measurement and the provision of means and methods for making measurements consistent with these standards; the determination of physical constants and properties of materials; the development of methods and instruments for testing materials, devices, and structures; advisory services to government agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; and the development of standard practices, codes, and specifications. The work includes basic and applied research, development, engineering, instrumentation, testing, evaluation, calibration services, and various consultation and information services. Research projects are also performed for other government agencies when the work relates to and supplements the basic program of the Bureau or when the Bureau's unique competence is required. The scope of activities is suggested by the listing of divisions and sections on the inside of the back cover.

Publications

The results of the Bureau's research are published either in the Bureau's own series of publications or in the journals of professional and scientific societies. The Bureau itself publishes three periodicals available from the Government Printing Office: The Journal of Research, published in four separate sections, presents complete scientific and technical papers; the Technical News Bulletin presents summary and preliminary reports on work in progress; and Basic Radio Propagation Predictions provides data for determining the best frequencies to use for radio communications throughout the world. There are also five series of nonperiodical publications: Monographs, Applied Mathematics Series, Handbooks, Miscellaneous Publications, and Technical Notes.

A complete listing of the Bureau's publications can be found in National Bureau of Standards Circular 460, Publications of the National Bureau of Standards, 1901 to June 1947 ($1.25), and the Supplement to National Bureau of Standards Circular 460, July 1947 to June 1957 ($1.50), and Miscellaneous Publication 240, July 1957 to June 1960 (Includes Titles of Papers Published in Outside Journals 1950 to 1959) ($2.25); available from the Superintendent of Documents, Government Printing Office, Washington 25, D. C.

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT		**NBS REPORT**
1001-12-10411	November 27, 1961	7387

Test of the Mobilization Structure
Under Sustained Uniformly Distributed Load

by

L. F. Skoda

To

Bureau of Yards and Docks
Department of the Navy

IMPORTANT NOTICE

NBS

U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

Test of the Mobilization Structure Under Sustained Uniformly Distributed Load

L. F. Skoda

A 44- by 80-ft precast thin-shell panel frame structure was constructed for the purpose of evaluating erection techniques, structural stability and joint sealing materials. The problems encountered during erection can be mainly attributed to inadequate dimensional control of the precast units and handling techniques used after casting and during erection of the precast units; the difficulties during erection of the structure could have been avoided by strict adherence to more rigid dimensional control.

A uniformly distributed live load of 40 psf was applied to a two bent test section of the structure. A maximum deflection of 2 in. occurred at mid-span of the roof sections 5 months after application of the test load, as equilibrium was approached. Side wall movements were significantly large only at the west wall, with a maximum deflection of 0.4 in. evident at equilibrium 3 months after initiation of the test. Daily deflection variations were observed after equilibrium was reached which can be attributed to environmental changes.

The joint sealing materials used in the structure achieved their intended purpose but other sources of water penetration were apparent. The construction bolts that were exposed to the elements, particularly those used at the wall-roof connections, were a source of leakage. The more damaging source of leakage was through the transverse cracks that appeared in the webs of the roof panels. The exact cause of these cracks has not been precisely determined so that a solution to this problem is not apparent at this time.

1. INTRODUCTION

Among the problems confronting the engineer in the design of thin-shell precast concrete structures are the problems concerning casting and erection techniques, dimensional tolerances, watertightness of joints, and deflections under sustained loads. In order to develop the required information, a 44- by 80-ft experimental "Mobilization Structure" was erected on the NBS grounds at the request of the Bureau of Yards and Docks and a two-bent section of it was subjected to a sustained load test for a period of a year. This report summarizes the results of the observations made on the structure during the past year.

2. PROCEDURE

2.1 Description of Structure.

The "Mobilization Structure" illustrated in figure 1 is a precast thin-shell concrete building composed of 20 bents, each bent being 4-ft wide and spanning 44 ft. The bents are made up of two side wall and two roof panels that are essentially channel shaped in cross section. Fabrication of the building elements and erection of the structure were accomplished on the basis of a competitive bid contract.

The panels were fastened to one another by a system of bolted and welded connections. Inserts had been cast into the wall panels and footings that enabled a welded connection to be made between each wall panel and the footing. The knee joint (wall-roof connection) was made with lap welded splices of metal plates that were attached to the main reinforcing of each wall and roof panel prior to casting. The roof panels comprising each bent were joined together at the crown with two 3/4 in. D bolts that passed through transverse ribs located at the crown ends of the roof panels. Each bent was connected to the previous bent with a number of 3/4 in. D bolts. These bolts passed through pipe sleeves that were precast into the longitudinal legs of all panels. Closure of the structure was accomplished with end wall panels that were bolted to the first and last bents. Views of wall and roof panels, and joints between them are shown in figures 1 through 6.

2.2 Design of Test

The third and fourth bents from the south end wall were selected as the two bent test section. These particular bents were chosen because erection of the structure began at the north end wall, thereby enabling the contractor to develop an erection technique prior to erection of the test bents. The test section was purposely separated from the rest of the structure by a space of 1/2 in. The two test bents were bolted together but no connections were made to the adjoining bents.

The live load of 20 psf was used in the design of the structure. A uniformly distributed live load equal to twice the design load was applied to the test section. The test load consisted of pea gravel of known weight carefully screeded to a predetermined depth. The gravel was maintained at a uniform depth by a plywood framework that surrounded the test section. The plywood framework was arranged so that the two bents comprising the test section could be loaded separately.

2.3 Instrumentation

The displacements of the various points of the test panels were measured with 0.001 in. dial gages attached to pipe stands supported by the concrete floor in the structure. Deflection measurements were made at the quarter span and mid-span stations of the test section. Side wall movements were measured at the knee joints 8 ft from the floor and 2 in. above the wall floor interface. A sufficient number of gages were placed at each station so that any differential movement between the two adjoining test bents could be detected. Reference gages were also placed on the unloaded panels adjacent to the test section.

Elevation measurements were made of the floor slab under the test section with a Dumpy level and a Philadelphia rod. Bench marks were established on the footings at each side of the north end wall. A series of five stations were established at points as near as possible to the dial gage stands. Elevation measurements were made during the test to determine any movement of the floor slab so that the observed dial gage readings could be corrected.

In addition to deflection and elevation measurements, temperature measurements were made at various locations on the structure. Thermometers were attached to the dial gage stands, to the bottom of the longitudinal legs and to the under side of the webs of the roof panels. Temperatures of the exposed roof surfaces adjacent to the test section were also measured.

2.4 Application of Load

The 40 psf test load was applied in increments of 10 psf. The two test bents were alternately loaded with 10 psf increments and deflection readings were made after each increment. The bents were loaded alternately in order to observe any differences in deflection due to the nonsymmetrical application of loads. After the entire test load was applied, the gravel was completely covered with a polyethelyne membrane in an effort to maintain the gravel at a constant weight during any future periods of inclement weather.

2.5 Collection of Data

The deflection measuring system was installed two weeks before the test load was scheduled to be applied. A number of preliminary readings were taken in order to establish the time of day that the deflections caused by environmental changes were at a maximum. The results of these readings indicated that the maximum deflection occurred at 11:30 A.M. (EST) and it was decided to take all subsequent readings at this time.

At 11:30 A.M. on the day that the test load was applied, a set of zero readings were taken on all dial gages and elevation stations. The test load was then applied, as previously described, in 10 psf increments to alternate bents with a complete set of readings being made before and after each increment. The total load of 40 psf was applied by 2:30 P.M. on the same day at which time a final set of readings was taken. Subsequent readings were made on all dial gages according to the following schedule: first 30 days, daily; next 60 days, bi-weekly; next 9 months, bi-monthly; after the first year, monthly.

The reference gages measured movements of the unloaded panels adjacent to the test section. As these adjacent panels were bolted to the structure along one edge only, it was felt that deflection measurements of unloaded panels that were bolted along both edges would be more significant. Consequently, one month after application of the test load, additional gages were placed at the crown and knee joints of a bent located halfway between the test section and the north end wall.

Five months after the test began the deflection measuring system was modified. Mechanical difficulties necessitated the elimination of the gages measuring the quarter span deflection and the gages measuring wall movements 2 in. above the floor. The gages at the knee joints and crown were rearranged to measure average movements at each station rather than movements of individual panels. The reference gages at the adjacent panels and at the middle of the structure were allowed to remain undisturbed.

3. RESULTS

3.1 Instantaneous Deflections During the Loading Period

The differential deflections anticipated as a result of alternate bent loading did not materialize. Figure 7 indicates the deflection vs. applied load at the crown and quarter points. The applied load notation refers to the amount of load applied to each bent (i.e., 0-10 means 0 psf on the north bent and 10 psf on the south bent). Although these curves represent the average deflection across the profile of each station, the load-deflection curves were essentially identical for individual bents.

Side wall movements did not become significant until the entire live load was applied. Measurements made at the kneee joints (8 ft above the floor level) indicated an average outward movement of .045 in. at maximum load. Measurements made 2 in. above the floor indicated an average outward movement of .002 in. at maximum load.

3.2 Deflections After One Year

Figure 8 is a graphic presentation of the deflection at the crown and quarter points plotted against the duration of sustained load. The deflection at the crown increased at a rapid rate for the first 20 days. The rate of increase became essentially linear for the next 100 days. From the 120 day period until the structure was under test for a year the deflection at the crown increased at a rate of approximately .01 in. per month, with a total one year deflection of 2.07 in.

The quarter point deflection measured just after application of the 40 psf load was .23 in. This initial deflection doubled after one day and increased to .92 in. after 148 days. As previously mentioned, mechanical difficulties necessitated the elimination of these gages after 148 days.

Side wall movements at the knee joints and footings are shown in figure 9. Very little lateral movement was observed at the knee joint in the east side wall, the maximum being .08 in. 135 days after the beginning of the test. The west side wall stabilized to an average outward movement of .4 in. approximately 3 months after the beginning of the test. Side wall movements measured at the footings followed the displacement pattern observed at the knee joints.

A comparison of movements at the crown of panels adjacent to the test bent and panels near the center of the structure is made in figure 10. The gages near the center of the structure were placed in service approximately a month after the test began so that the comparison of deflections could only be made from that time on. Movement of the panels adjacent to the test bents agreed very closely with those observed near the center of the structure. This agreement indicates that the entire roof section acts as a unit when subjected to environmental changes.

3.3 Effects of Snow Loads and Temperatures

The deflections observed at times when the structure was subjected to various snow loads are indicated on figures 8 through 10. The deflection observed during the first snow load of 7 in. shows an expected increase in deflection at the crown accompanied by lateral movement of the side walls. The second snow load of 6.5 in. was preceded by heavy rainfall and a sudden freeze. This unusual moisture condition in the panels and formation of ice in the open joint between the test bents and the rest of the structure resulted in erratic movements at all gage stations. The third snow load of 7.5 in. was preceded by dry weather and the observed deflections conformed to those normally expected. The snow loadings did not appear to produce any lasting effects as deflection recovery occurrred after each thaw.

Temperature measurements were taken at various positions on the structure at the same time as deflection measurements. The difference in temperature of the roof surfaces and the underside of the longitudinal legs of the panels have been as high as 30° or more. Although an attempt was made

to correlate these temperatures and temperature differentials with observed deflections, no direct correlation was found to exist between temperature and deflections. It appears that other factors such as changing moisture conditions of the concrete must be considered.

4. SUMMARY

1. The instantaneous deflections at maximum load of the crown, quarter points and knee joints were .380, .236, and .045 in. respectively with no differential deflections observed due to alternate bent loading.

2. The equilibrium deflection at the crown was reached 5 months after application of the 40 psf test load and was approximately 2 in.

3. Side wall movements were only significantly large at the west wall which attained a maximum stable deflection of 0.4 in. 3 months after initiation of the test.

4. Deflection measurements taken of unloaded panels at various locations within the structure show that the entire roof system acts as a unit when subjected to environmental changes.

5. The effects of snow loading are temporary and full recovery was observed after melting.

6. Daily variations in deflection of precast concrete panels cannot be attributed to temperature alone but must include the moisture condition of the concrete.

5. GENERAL OBSERVATIONS

A number of observations were made during and after erection of the structure that were not directly related to the load test but are of sufficient importance to warrant discussion.

5.1 Dimensional Tolerances

It is noted that the firm responsible for casting the panels used in the Mobilization Structure is a reputable concern with a great deal of experience in precasting techniques. An inspection of the forms used to cast the panels revealed that the firm did a commendable job of form construction with the personnel involved displaying a great interest in these particular panels as well as the future of this type of construction. The forms were constructed of sheet steel and structural shapes that were welded

together and adequately braced to prevent displacements during casting. With all of the precautions taken to insure accuracy in casting, the length of the completed structure was 2 in. in excess of the specified length. If the observed departure of 2 in. in 80 ft, or 1 part in 480 is considered excessive, it is clear that specifications must be prepared which will require a higher degree of dimensional control than is now available in a commercial plant experienced in precasting operations.

5.2 Erection of Precast Members

Another important point to be considered in the construction of a building such as the Mobilization Structure is the method used to move the panels after casting and during erection. The lifting rig devised to position the roof panels in the structure consisted of a stiff back that was bolted to the panels by means of four threaded inserts that had been cast into each panel. The side walls were positioned in a similar fashion with a stiff back bolted to the top of each panel by means of two threaded inserts. Figures 2 and 3 show panels being positioned with a crane.

This system of moving the panels proved successful in that no panels were lost through breakage or severe damage. However, two objectionable features resulted from the use of this system. Cracks developed across the webs of each roof panel between opposite pairs of inserts. These cracks indicate that a plane of weakness was created by the insert cavities. After erection of the building was completed the insert cavities were filled with dry grout. These grout plugs appeared sound prior to the winter season, but after a number of cycles of freezing and thawing the bond between the panels and the plugs was destroyed to such an extent that the plugs could be simply lifted out of the cavities. These results indicate that the panels must be adequately reinforced in the vicinity of the embedded inserts, and that greater care must be taken in grouting the insert cavities. In the future, the insert cavities will receive a coating of epoxy/Thiokol adhesive prior to grouting, a system which proved to be successful in grouting welded joints of precast concrete panels - (See NBS Report 6682).

5.3 Bolted Connections

The third point to be considered in this discussion deals with the system of bolts used between bents. The first indication of an existing problem was realized on the morning of the second day of erection. The first three bents had been erected on the first day with all bolts in place and only hand tightened. The following morning an inspection of the three bent section revealed visible cracks between the vertical ribs and the webs of the side wall panels. Further investigation revealed

that the bolts were so tight that they could not be easily loosened with a wrench. The conclusion reached was that the tightening of the bolts resulted from the temperature drop that occurred between 4:00 P.M. of the first day and 8:00 A.M. of the second day. With this experience in mind the erectors installed all subsequent bolts in the wall panels with a very minimum of tightening.

Another problem brought about by the use of the bolt system is that each bolt exposed to weathering is a source of water leakage during rainy weather. The bolts at the knee joints in particular exhibited a tendency to permit the passage of water. The reason for this is that water running off the roof follows the contour of the upper wall section and passes through the bolt holes. The same problem is evident at the bolted connections between wall panels but with less severity than was observed at the knee joints. The elimination of exposed bolts would, of course, be the ideal solution to the problem and future design considerations should be directed towards this end.

5.4 Cracks in Webs of Roof Panels

It was observed a number of months after erection of the structure that the webs of all roof panels exhibited transverse cracks spaced approximately 2 ft apart along their lengths. These cracks were large enough to produce visible damp spots on the under side of the panels during any rain storm. When a continuous light rain or a sudden heavy rain storm occurred sufficient water leaked through the cracks to completely wet the floor area.

The first explanation advanced for these cracks was that they occurred as a result of drying shrinkage. An investigation was undertaken to produce similar cracking in scaled down laboratory size specimens similar to the roof panels. Although this investigation is not complete, indications are that shrinkage alone does not account for the formation of transverse and longitudinal cracks in the webs. The present hypothesis is that these cracks were caused by a combination of drying shrinkage and thermal stresses resulting from temperature differentials between the longitudinal legs and webs of the panels.

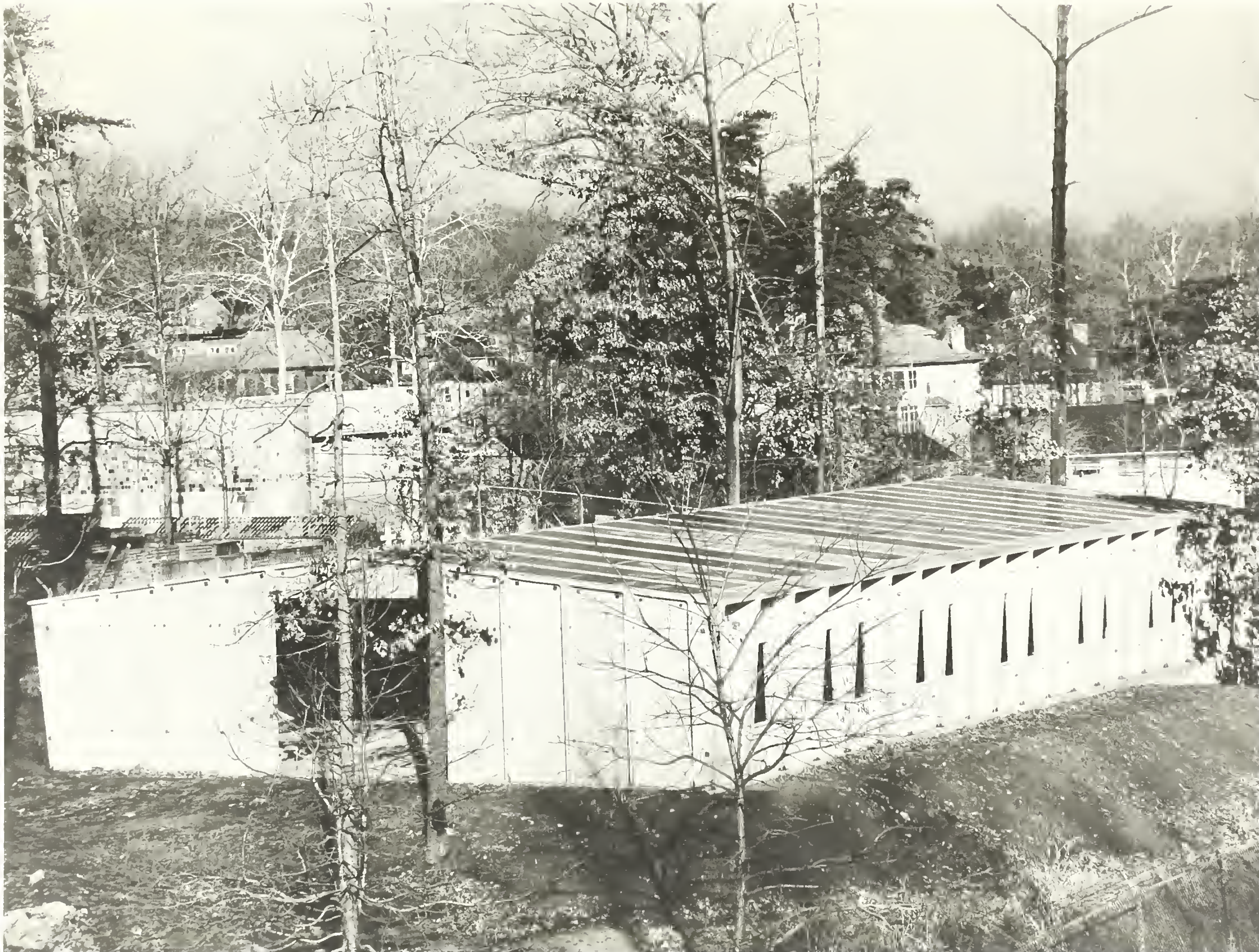


FIG. I. MOBILIZATION STRUCTURE

FIG. 3. ROOF PANEL BEING SWUNG INTO POSITION

FIG. 4. BOLTING ROOF PANELS TOGETHER AT RIDGE JOINT

FIG. 5. BOLTING ROOF TO SIDE WALL PANELS AT KNEE JOINT

FIG. 6. WELDING ROOF TO SIDE WALL PANELS AT KNEE JOINT

DEFLECTION AT CROWN AND QUARTER POINTS OBSERVED DURING APPLICATION OF LOAD

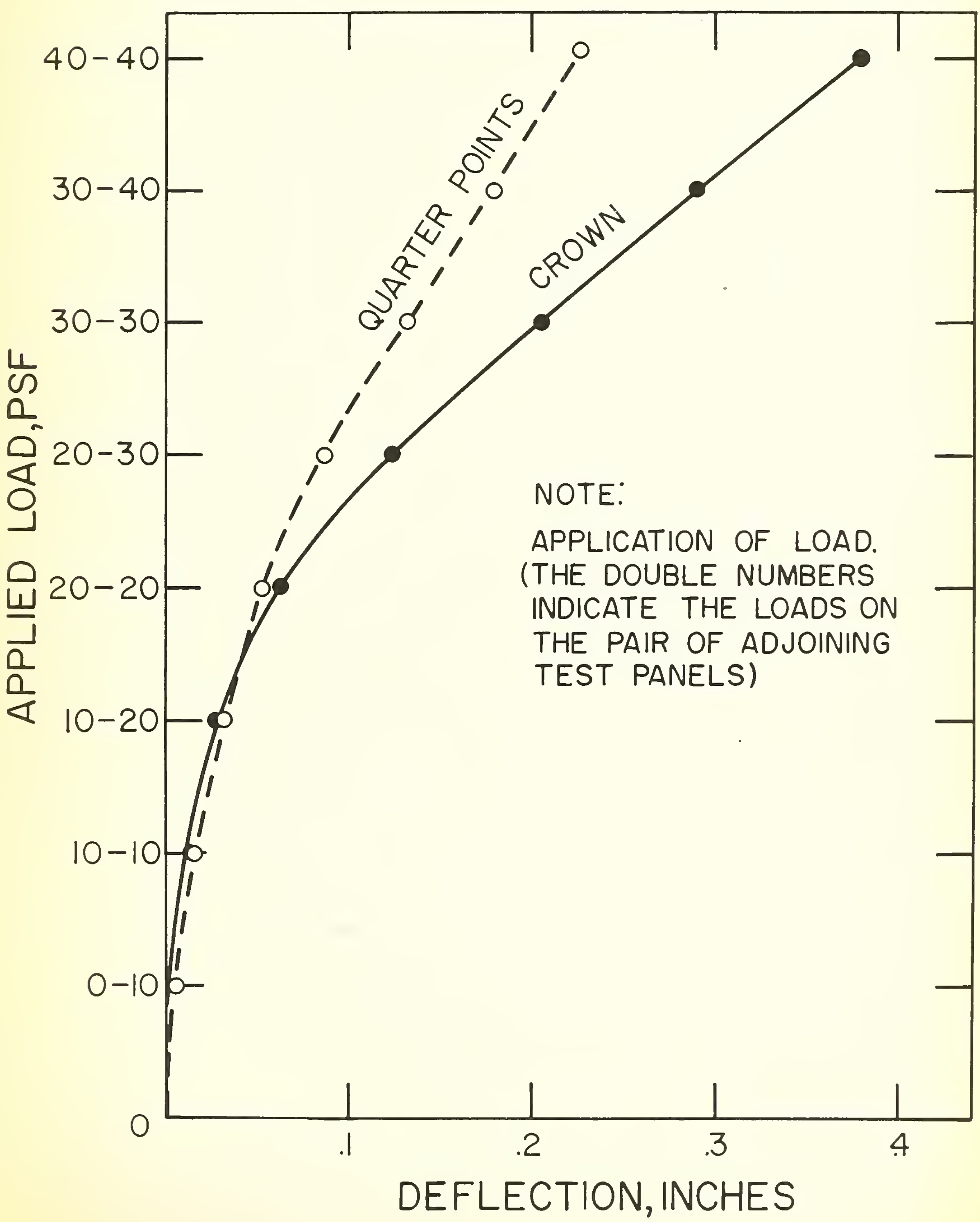


FIG. 7

DEFLECTION AT CROWN AND QUARTER POINTS UNDER SUSTAINED UNIFORMLY DISTRIBUTED LOAD OF 40 PSF.

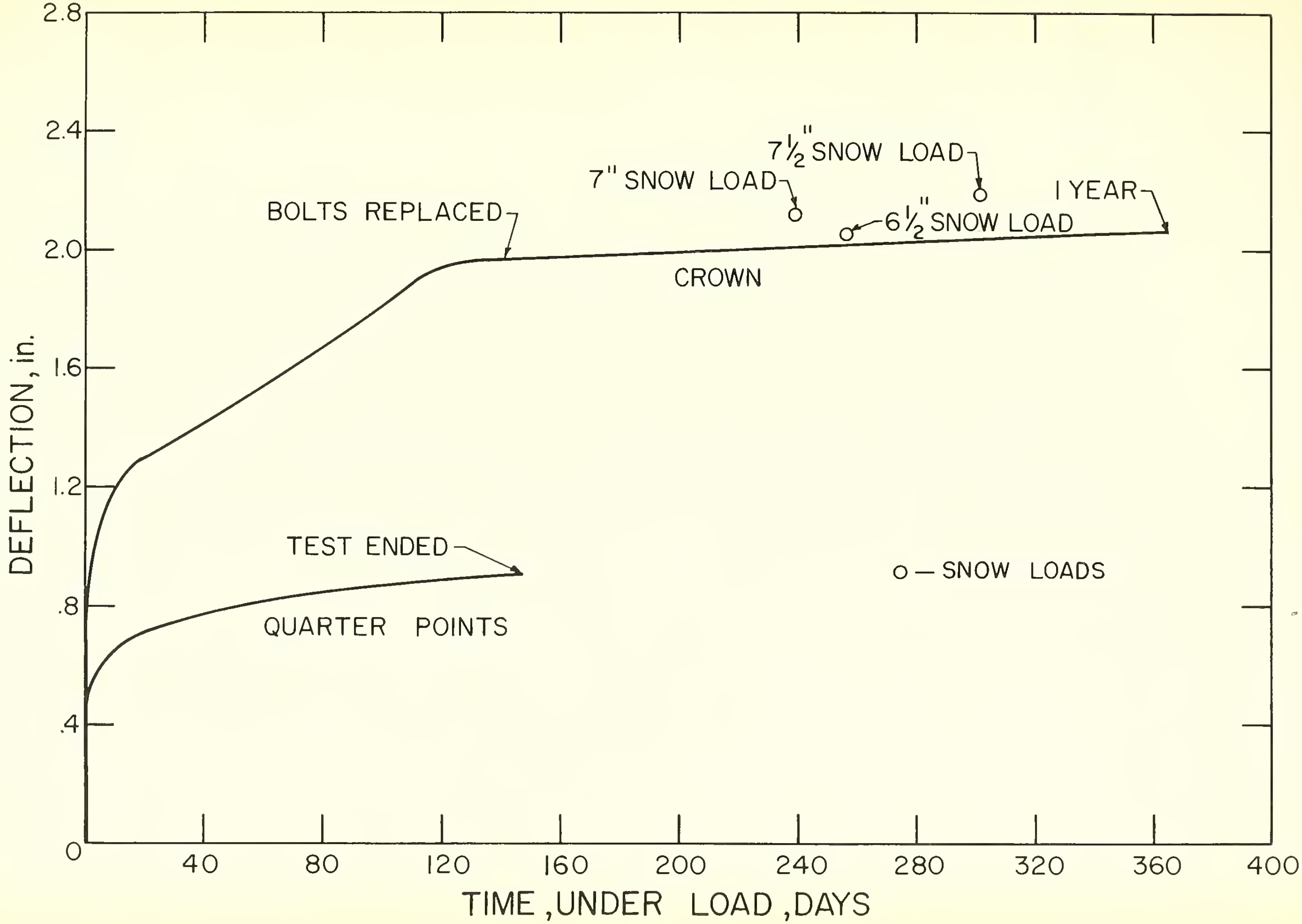
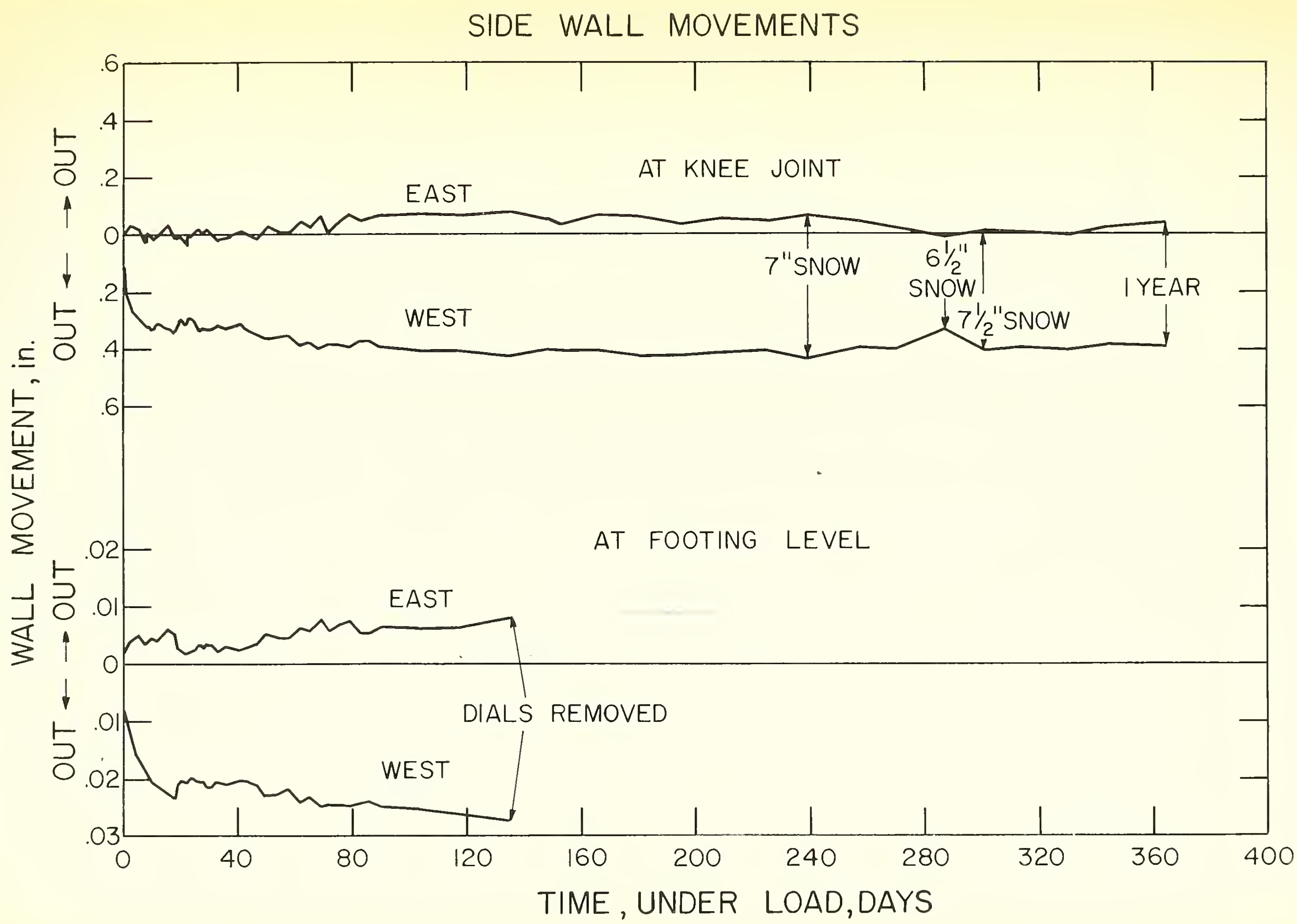


FIG. 8



SIDE WALL MOVEMENTS
AT KNEE JOINT
EAST
WEST
7"SNOW
6½" SNOW
7½"SNOW
1 YEAR
AT FOOTING LEVEL
EAST
WEST
DIALS REMOVED
WALL MOVEMENT, in.
OUT ← → OUT
.6
.4
.2
0
.2
.4
.6
.02
.01
0
.01
.02
.03
0
40
80
120
160
200
240
280
320
360
400
TIME, UNDER LOAD, DAYS

FIG. 9

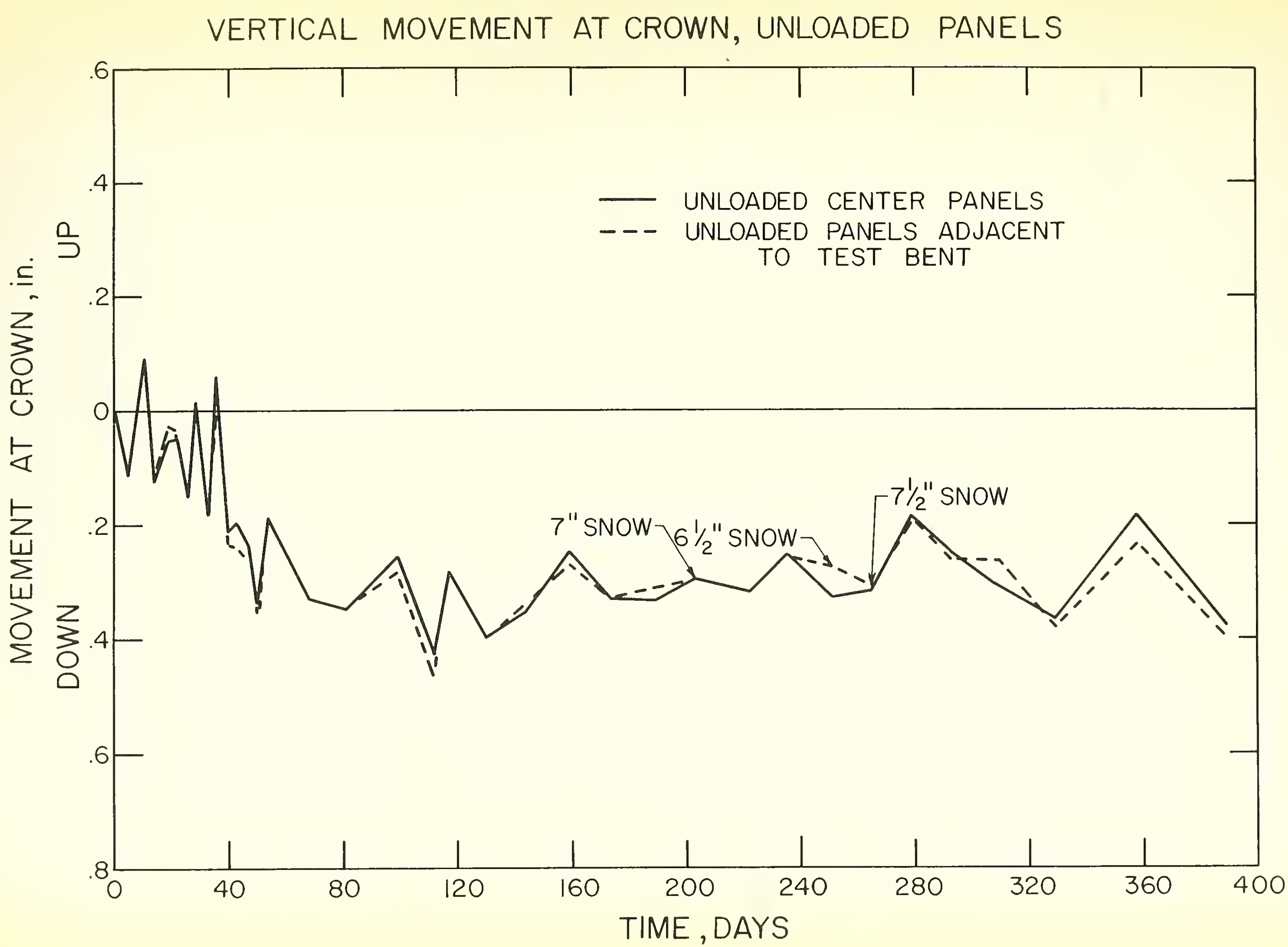

VERTICAL MOVEMENT AT CROWN, UNLOADED PANELS
UNLOADED CENTER PANELS
UNLOADED PANELS ADJACENT TO TEST BENT
7" SNOW
6 1/2" SNOW
7 1/2" SNOW
MOVEMENT AT CROWN, in.
UP
DOWN
.6
.4
.2
0
.2
.4
.6
.8
0
40
80
120
160
200
240
280
320
360
400
TIME, DAYS

FIG. 10

U. S. DEPARTMENT OF COMMERCE
Luther H. Hodges, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

WASHINGTON, D.C.

Electricity. Resistance and Reactance. Electrochemistry. Electrical Instruments. Magnetic Measurements. Dielectrics.

Metrology. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Scale. Volumetry and Densimetry.

Heat. Temperature Physics. Heat Measurements. Cryogenic Physics. Equation of State. Statistical Physics.

Radiation Physics. X-ray. Radioactivity. Radiation Theory. High Energy Radiation. Radiological Equipment. Nucleonic Instrumentation. Neutron Physics.

Analytical and Inorganic Chemistry. Pure Substances. Spectrochemistry. Solution Chemistry. Standard Reference Materials. Applied Analytical Research.

Mechanics. Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Rheology. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics. Electrolysis and Metal Deposition.

Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Crystal Growth. Physical Properties. Constitution and Microstructure.

Building Research. Structural Engineering. Fire Research. Mechanical Systems. Organic Building Materials. Codes and Safety Standards. Heat Transfer. Inorganic Building Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics. Operations Research.

Data Processing Systems. Components and Techniques. Digital Circuitry. Digital Systems. Analog Systems. Applications Engineering.

Atomic Physics. Spectroscopy. Infrared Spectroscopy. Solid State Physics. Electron Physics. Atomic Physics.

Instrumentation. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

Physical Chemistry. Thermochemistry. Surface Chemistry. Organic Chemistry. Molecular Spectroscopy. Molecular Kinetics. Mass Spectrometry.

Office of Weights and Measures.

BOULDER, COLO.

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Cryogenic Technical Services.

Ionosphere Research and Propagation. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services.

Radio Propagation Engineering. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation-Terrain Effects. Radio-Meteorology. Lower Atmosphere Physics.

Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time Interval Standards. Electronic Calibration Center. Millimeter-Wave Research. Microwave Circuit Standards.

Radio Systems. High Frequency and Very High Frequency Research. Modulation Research. Antenna Research. Navigation Systems.

Upper Atmosphere and Space Physics. Upper Atmosphere and Plasma Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.

NBS