NATIONAL BUREAU OF STANDARDS REPORT

5783

SUMMARY REPORT

ON

FIRE RESISTANCE OF REINFORCED CONCRETE

by
J. V. Ryan

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. A major portion of the Bureau's work is performed for other Government Agencies, particularly the Department of Defense and the Atomic Energy Commission. The scope of activities is suggested by the listing of divisions and sections on the inside of the back cover.

Reports and Publications

The results of the Bureau's work take the form of either actual equipment and devices or published papers and reports. Reports are issued to the sponsoring agency of a particular project or program. Published papers appear either in the Bureau's own series of publications or in the journals of professional and scientific societies. The Bureau itself publishes three monthly periodicals, available from the Government Printing Office: The Journal of Research, which presents complete papers reporting technical investigations; the Technical News Bulletin, which presents summary and preliminary reports on work in progress; and Basic Radio Propagation Predictions, which provides data for determining the best frequencies to use for radio communications throughout the world. There are also five series of nonperiodical publications: The Applied Mathematics Series, Circulars, Handbooks, Building Materials and Structures Reports, and Miscellaneous Publications.

Information on the Bureau's publications can be found in NBS Circular 460, Publications of the National Bureau of Standards ($1.25) and its Supplement ($0.75), available from the Superintendent of Documents, Government Printing Office, Washington 25, D. C.

Inquiries regarding the Bureau's reports should be addressed to the Office of Technical Information, National Bureau of Standards, Washington 25, D. C.

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT		NBS REPORT
1002-12-4872	February 11, 1958	5783

SUMMARY REPORT

ON

FIRE RESISTANCE OF REINFORCED CONCRETE

by
J. V. Ryan

Report to
Office of the Chief of Engineers
Bureau of Yards and Docks
Headquarters, U. S. Air Force

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

SUMMARY REPORT

ON

FIRE RESISTANCE OF REINFORCED CONCRETE

ABSTRACT

An investigation was undertaken to determine the effects of certain variables on the fire resistance of reinforced concrete. A theoretical approach was followed with subsequent actual fire tests. The results obtained indicate that a good start has been made on the investigation of the effect of cover thickness and that the theoretical method is worthy of further study.

---

1. INTRODUCTION

During tests to evaluate the fire endurance of roof deck systems (1), the reinforced concrete beams used to support the decks failed to perform as well as anticipated from the usual design practices. Beams that had been expected to provide support of as much as four hours to the roof decks, if needed, became unsatisfactory in as little as 49 minutes. This raised serious doubts as to the adequacy of the existing information upon which reinforced concrete beams, and other structural elements, were designed to have the necessary fire resistance.

Experience from actual fires and a limited number of fire tests had shown that concrete structures often spalled under fire exposure, leading to partial or complete loss of the protective thickness. However, this spalling had not followed any clear pattern and several theories have been advanced to explain the causes. Unfortunately some of the various theories disagreed with others.

In view of the obvious need for data, an investigation of the factors affecting the fire resistance of reinforced concrete was undertaken. Among the factors of interest were thickness of protective cover and period of aging. The study has been initiated successfully and valuable data obtained. However, the lack of available funds has made it necessary to cease activity at the present time. This report is a summary of the progress to date.

2. PLAN OF THE INVESTIGATION

The problem was attacked along two lines, theoretical and experimental. The theoretical phase was undertaken first and the experimental phase designed not only to study factors affecting the fire resistance of reinforced concrete but also to explore the usefulness of the theoretical method.

2.1 Theoretical Phase

The theoretical study was made by digital computer calculations of two dimensional heat flow. The differential equations expressing the heat flow by conduction in solids and those expressing the applicable boundary conditions were modified to difference equations in order that the digital computer could be employed. The effects of moisture, phase changes in the concreting materials, changes in the thermal properties, and the mechanical behavior of concrete when exposed to high temperatures are factors affecting the fire endurance. These factors are not all well understood so that allowance for them could be made only approximately in setting up the equations. The complexity of the problem was such that the capacity of the available computer was a limiting factor. These approximations and limitations required that the results of such calculations be used with caution. It is believed, however, that this method can lead to the development of scaling relationships by which estimates may be made of the probable behavior of reinforced concrete structures when experimental results for similar structures are available. The work and results of this phase were summarized in a report (2) submitted to the sponsors in September 1956. Further work under this phase since that date has involved preparations to obtain more accurate solutions of the equations by utilization of a recently acquired computer of greater capacity. However, the available funds were expended before any results could be obtained. Therefore, the remainder of this report will be concerned with the experimental phase and comparisons between the results.

2.2 Experimental Phase

The experimental phase of the program was designed to provide a basis for evaluation and verification of the results of the theoretical method. The heat flow equations had been applied to concrete T-beams with top slabs that extended far enough from the beams to permit consideration of them as simple slabs, for heat flow behavior. Therefore, the experimental work was made up of fire exposure tests of a series of T-beams and a series of slabs.

3. SPECIMENS AND MATERIALS

The beams were 17 ft in overall length and had cross-sections in the shape of a T. In order to simplify both the fabrication and testing of the beams and still permit a considerable range of cover thickness for the reinforcing bars, the only variables were the overall beam depth and the horizontal spacing of the main reinforcement. The top slabs of the T's were 5 in. thick and 46 in. wide approximately. The stems of the T's were approximately 11 3/4 in. wide and of depths that differed from specimen to specimen. The beam reinforcement consisted of six longitudinal No. 8 deformed bars with nine No. 3 deformed bar stirrups near each end. The top slabs were reinforced with two No. 5 and three No. 3 longitudinal deformed bars and with transverse No. 4 deformed bars. The six No. 8 bars were placed in three pairs, the vertical center-to-center distance between pairs being 2 in. The horizontal distance between the bars within each pair was determined by the amount of cover to be provided. The distance from the top surface of the finished specimen to the midheight of the group of No. 8 bars was the same in each specimen so that each beam would have the same total design load. A 2- by 4-in. rectangular mesh wire fabric was placed in contact with the bottom and sides of the beam reinforcing bars and the bottoms of the top slab bars of all the specimens except that having the least cover. The general arrangement of the reinforcement is shown in figure 1.

The assembled reinforcement for each beam specimen was placed in a form which was then filled with concrete. An electric powered vibrator was used during the pouring of the concrete. The concrete was mixed 1 part by weight of Portland cement, 4.1 parts sand, 3.4 parts gravel; with a water/cement ratio of 0.90. The maximum allowed gravel size was 3/4 in. for beams to have cover of greater than 1 in. and 3/8 in. (White Marsh pea gravel) for the beams to have cover of 1 in. or less. The sand was a bank sand with an appreciable proportion of small gravel included.

The beam depths and horizontal spacing of the No. 8 bars were set to provide nominal covers of 1/2, 1, 2, and 4 in. Each beam was left in the form several weeks and then stored in a building that was well ventilated during good weather and heated during colder weather. They were stored for periods of about 2 years before test, during which time measurements were made to indicate the state of drying. These measurements were made by means of humidity sensing devices in tubes extending into the concrete. The ends of the tubes in the concrete were open but those outside were sealed. The devices gave indications of the relative humidity of the air enclosed in the tubes. Assuming that moisture equilibrium was reached between the air and concrete, these relative humidity readings may be related to the moisture content of the concrete in the vicinity of the open end of the tubes.

The slab specimens were each 2 ft square. They were made to nominal thicknesses of 1, 2, 3, and 4 inches. Two slabs were cast of each thickness. No reinforcement was used in the slabs. Tubes to permit humidity measurements were placed in the forms for four of the eight specimens before the concrete was poured. The concrete for the slabs was the same mix as that for the T-beams. However, only the 3/8 in. maximum pea gravel was used for coarse aggregate. After each slab was removed from the forms, it was stored in a room maintained at approximately 70°F and 50 percent relative humidity. The slabs were stored for periods up to nine months before test.

Thermocouples had been attached to the reinforcing bars of the beams before they were placed in the forms. Similar thermocouples were placed in the slab forms before the concrete was poured. The locations of the couples are indicated in figure 2.

4. TEST PROCEDURE

The specimens were placed in furnaces appropriate to their sizes and exposed to fires controlled to produce, as closely as practicable, the temperatures of the standard time-temperature curve defined in ASTM Standard Method for Fire Test of Building Construction and Materials, E-119, which include: 1000°F at 5 min, 1300°F at 10 min, 1550°F at 30 min, 1700°F at 1 hr, 1850°F at 2 hr, and 2000°F at 4 hrs.

4.1 Beam Tests

Each beam was placed along the longitudinal center-line of the large floor-test furnace. Each end rested on a short section of steel beam suspended from a heavy I-beam frame. The supports were provided with means for cooling by circulating water and were enclosed, with the ends of the beams, in brick and plaster. The exposed length of each beam was approximately 14 ft. Separately supported slabs were used to close the remainder of the furnace opening. A gap of about 3 in. width between each side of the T-beam top slab and the filler slabs was filled with mineral wool or glass fiber insulation.

The applicable Standard Test Method specifies that load-bearing building components shall be tested under a load calculated to develop the working stresses contemplated in the design. It further specifies that the specimen shall sustain this load throughout the fire test. However, it does not specify what shall constitute failure to sustain the load. Various criteria have been considered as an aid to the determination of load failure, including the combination of a deflection and a rate of deflection, the values of which are related to dimensions of the specimen.

The beams were loaded at four points, 2 and 6 ft on each side of center, through rollers on bearing plates laid on the top surface. Each beam was subjected to a total load of 59600 lb, including the dead weight of the beam. This load was designed to stress the steel to 20,000 psi. The beam with 2 in. cover was tested without full load in order to reduce the moisture content. It had been intended to retest it with full load later but the beam suffered some damage during the initial exposure. Therefore, it was retested without full load.

The fire exposure of each beam, except the non-loaded exposures of the 2 in. cover beam, was continued until a net deflection of at least 2.5 in. was attained. The test of the beam with 1/2 in. cover was continued after this deflection had been reached and the load removed in order to obtain additional temperature data.

Temperatures were recorded from the thermocouples in the furnace, on the reinforcing bars, in the concrete, and on the unexposed surfaces. Each beam was broken up after test in order to determine, if possible, the actual cover thicknesses achieved and the actual positions of the thermocouple junctions.

4.2 Slab Tests

The small slabs were tested in a furnace having an opening of about 22 in. square. The slabs were laid on the top of the furnace to close this opening. The edges of the slabs were insulated with fire brick and mineral wool to minimize lateral heat loss. A metal pan, painted black, in which water was circulated, was positioned about 6 to 9 in. above the unexposed surfaces of the slabs. This pan acted as an absorber of the heat energy radiated from the specimens and thus served to provide some control of ambient conditions. Measurements of the flow rates and temperature rises of the water were made to give an indication of the rate of heat transfer. Of the two slabs of each thickness, one was tested with a thermocouple, under a 6 in. square by 0.4 in. thick felted asbestos pad, at the center of the unexposed surface, and the other was tested without either thermocouple or pad. Unexposed surface temperature indications were also obtained by commercial marking pencils, the marks of which were stated by the manufacturer to melt at selected temperatures. Temperatures were recorded from thermocouples in the furnace, in the concrete, and as mentioned, on the unexposed surfaces of half the slabs. The fire exposures were continued until temperatures in excess of 1000°F had been indicated by all the thermocouples in the concrete. No load was applied to any of the slabs.

Following each test, the slab was examined and broken up to determine the actual depths from the exposed surface to the thermocouple junctions and the actual thickness of the slab.

5. RESULTS

The humidity data from the beams were obtained by cards with spots of dyes each of which changed color over certain humidity ranges. Color change of all the spots indicated relative humidity of over 80 percent. The cards were placed in the pipes extending into the concrete, and the open ends of the pipes than capped. Throughout the aging periods of the beams, not only did all the spots change color but the dyes ran and the cards felt damp when removed from the pipes. This was taken to indicate that the relative humidity of the air in the pipes was in the range of 95 to 100 percent. Consequently it is evident that the concretes at the centers of the beams were still wet after almost two years of aging.

The humidity data from the 2 ft square slabs were obtained by electrical resistance type humidity sensing elements, each sealed into a pipe fitting attached to close one end of a copper tube extending into the center portion of one of the slabs. The length to inside diameter ratio of the tubes was very large as was the ratio of the volume of air surrounding the sensing element to the area of the end of the tube open to the concrete. These two factors made the system very slow to come to equilibrium and, therefore, insensitive to short-time fluctuations. The aging of the slabs in a constant temperature and humidity room eliminated or greatly reduced such fluctuations so that the slow approach to equilibrium was the chief drawback. The data indicated increasing relative humidity for about the first month during which readings were taken. Since the moisture content of the concrete would have been decreasing from its initial high value or have reached an equilibrium value during this period, it must be assumed that the increasing humidity readings indicated that the air in the copper tube and pipe fitting systems was still coming to moisture equilibrium. For the remaining several months, the relative humidity values from three of the four specimens leveled off. The readings at about six months were in the range of 51 to 54 percent. Since the specimens had been in a room maintained at about 50 percent relative humidity, the data shows they had come to uniform moisture content throughout, in moisture equilibrium with the surrounding atmosphere.

Although the primary purpose of the fire exposure tests was the accumulation of data on the time-temperature history at various depths and locations within the specimens when the standard time-temperature exposure occurred on the appropriate surface, the T-beams were tested in compliance with the standard method for determining fire endurance. Therefore, the results of these tests are reported with both temperature history and fire endurance in mind.

5.1 Fire Endurance of T-beams

The fire endurance of reinforced concrete beams is determined by failure to support the design load. The beams with 1/2, 1, and 4 in. cover were tested under load and reached net deflections that raised doubts as to their ability to sustain the load further at 1 hr 6 min, 1 hr 58 min, and 5 hr 20 min, respectively. The behaviors of the individual beams were much the same in their respective tests. In all but the test of the beam with 1 in. cover, concrete sloughed off along each arris at the bottom of the beam, in lengths from a few feet to nearly full length and up to depths sufficient to expose part of the bottom No. 8 reinforcing bar. This loss of concrete started within the first 10 to 15 min and continued intermittently throughout the test. There were not, ordinarily, any distinct sounds associated with the sloughing, nor any other evidence of spalling of some violence. In addition to the sloughing of concrete, cracks formed and enlarged in the beam stem and top slab. Those in the beam stem were mostly tension cracks, extending across the soffit and up each side. Those in the top slabs extended up the sides but varied from short, and full width, transverse cracks to nearly full length longitudinal cracks. Examples of the cracking and sloughing of concrete are shown in figures 3, 4, 5, and 6. The deflections of the loaded beams increased throughout their tests except for the beam with 4 in. cover. This beam was loaded to about .8 of the design applied load for the first 1 hr 15 min, during which period the deflections increased at first and then decreased. The application of full design load required the substitution of a different regulator in the loading system. This was done between 1 hr 15 min and 1 hr 30 min, after which time the full design load was applied. After the full load application, the deflection curve was of the same general form as those of the other fully loaded beams. The beams with 1/2 and 1 in. cover were under full load from the start of the fire exposure. The deflection curves are shown in figure 7.

5.2 Time-temperature History

The temperature data obtained from the several thermocouples on the reinforcing bars and in the concrete of the T-beams and the 2 ft square slabs were examined to determine the times at which temperature of 1000°F was attained at each location. Most steels used in reinforcing bars have yield strength values at 1000°F equal to about 50 percent of their room-temperature values. Because of this and the fact that safety factors of two are usually involved in design of such specimens, this temperature is often taken to be critical in evaluating the protection afforded steel by various materials, and is sometimes considered an indication of the imminence of load failure. However, for the loaded beams, the times at which load failure occurred were significantly greater than the times at which this temperature was first reached at one of the thermocouples on the No. 8 steel bars. This should be expected since the beams included bars of this size that had cover from the bottom greater than the minimum. In none of the beam tests was this temperature observed on all the No. 8 bars. It is believed, however, that the attainment of this temperature may be taken as an indication of the approximate time that load failure should be expected for beams having only two main reinforcing bars, so located that each bar has equal side and bottom cover. As in all but one of the tests discussed herein, fire exposure of reinforced concrete beams often results in sloughing or spalling of concrete, especially from the arrises, to reduce the thickness of cover for the steel reinforcement. The loss of cover reduces the time required for temperature rise in the steel and, therefore, the time to load failure. On the other hand, adequate means to retain the concrete in place may be expected to increase the fire resistance to be obtained from a given beam. Since the theoretical method assumed no sloughing, the predicted values should more nearly agree with the performances of beams designed to prevent or reduce sloughing.

The temperature data, as translated to time-to-1000°F, was compared with the time for equivalent beams or slabs as predicted by the theoretical precedures previously carried out. The results are presented in the form of correlation charts, or plots of the actual times observed in tests against the times predicted by theory. Figures 8 through 10 are these charts. The solid line in each corresponds to a 1-to-1 correlation, or full agreement between experiment and theory.

6. DISCUSSION

The sloughing of concrete from the beams gives an indication of the effectiveness of the wire fabric placed outside the bar reinforcement. The fact that the 1 in. cover, with fabric, remained intact whereas the 1/2 in. cover sloughed badly indicates that the latter should have remained intact had fabric been included (See figures 3 and 5). Since the 2 in. and 4 in. covers sloughed despite the presence of the fabric, it appears that the fabric is not fully effective when placed far from the concrete surface. However, for beams in which the main reinforcing bars are to have covers of 2 in. or more, placement of the wire fabric at about 1 in. from the concrete surface may be expected to retain the cover during fires, and improve the beam's fire resistances over those of beams similar except for the use of such fabric.

The agreement between theoretical and actual heat transfer data is fairly good. In fact, it may appear to be better than it actually is. The theoretical value is determined on the basis of the thickness of cover for the reinforcing steel or for the thermocouple junction in the concrete. But, since the omission of the effect of the steel bars was a necessary simplification for the theoretical computations, this value is for a particular locus, a line perpendicular to the cross section in a beam or a plane parallel to the surfaces in a slab. However, the thermocouple junctions were beads of about 0.05 in. diameter and the main steel bars were of 1 in. diameter. Consequently, the actual temperatures observed were not those at particular points but represented the effect of heat flow across a concrete-to-metal surface into a volume. To permit comparisons with theoretical values, it was assumed that bar temperatures could be directly compared with computed temperatures of the concrete at a position corresponding to the center of the bar.

Another limitation on the quality of the correlation obtained is that due to uncertainty as to the precise locations of the thermocouple junctions and cover for the steel bars. Reasonable care was taken to support the bars and thermocouple junctions in the desired positions during the casting of the specimens. Following fire exposure, each specimen was broken up, the thermocouple leads traced, and the locations of the junctions measured where possible. However, the accuracy of these measurements was affected by the conditions of the specimens. The beams were tested until a minimum deflection was reached in most instances and the exposures continued well past the times at which 1000°F was reached. Many of the thermocouple leads were very brittle, as a result of the long exposure to high temperature, and broke during the breakup of the specimens. This, coupled with the sloughing of concrete from the beam arrises during tests, made the measurement of concrete cover for the bars at the thermocouple locations impossible in many cases. It was necessary to assume that the intended nominal cover had been achieved, but variation of 1/4 to 1/2 in. must be considered a real possibility.

The thermocouples in the slab portions of the beams were placed in holes drilled from the top surface at the time of preparation for test. The thermocouple junctions were placed in the holes which were filled with a loose granular insulator. The locations of the junctions were determined by measuring the lengths of leads in the holes. The measurements were probably accurate to about 1/16 to 1/8 in., in the 5 in. thick slabs, or about 1 to 2.5 percent of the total thickness.

The tests of the 2 ft square slabs were stopped shortly after 1000°F was reached at the thermocouple junction most remote from the exposed surface in each case. No concrete was sloughed from the surfaces and the thermocouple lead wires were less brittle than were those in the beams. Therefore the original surfaces were still intact and it was possible to measure the thermocouple junction locations to the nearest 1/32 in. in all cases and the nearest 1/64 in. (about 1/2 to 1/4 the junction bead diameter) in most cases. Consequently the correlation indicated in the figures is most meaningful for the 2 ft square slabs and least meaningful for the beam bars.

The data from the 2 ft square slabs more nearly approximates a straight line than either that for the beam bars or that for the slab portions of the beams. However, this line does not coincide with the 1-to-1 correlation line, nor is it parallel. It represents correlation between theoretical and actual values of about 4-to-3 for slabs without unexposed surface thermocouple pads.

The times-to-1000°F for the thermocouples in slabs with unexposed surface pads were significantly less than those for similarly placed thermocouples in slabs without pads. Thus, on concrete slabs of thicknesses at least up to 4 in., the presence of insulating overlays of limited lateral dimensions influences the temperatures within the slabs, and may be expected to influence the fire resistances of the slabs.

7. SUMMARY AND CONCLUSIONS

The fire endurance tests of the beams provided data on the fire endurances of particular constructions over a range of concrete cover thicknesses. These data should be of value in the design of reinforced concrete beams for desired fire resistances.

The tests point up the importance of the retention of all the concrete as cover to the structural reinforcement. The inclusion of wire fabric at about 1 in. from the concrete surface, or immediately outside the main bars in cases of cover less than 1 in., was shown to be both satisfactory and practicable as a means to achieve this end. The fabric employed had a 2- by 4-in. mesh, but a 4- by 4-in. mesh probably would have been adequate.

The tests of the beams and small slabs provided data upon which to make correlations with the predictions derivable from the theoretical work done previously. The correlations were fairly good, which indicates that the procedures followed and assumptions made in the theoretical analysis were reasonable. The fact that the correlations were not 1-to-1 may be due in part to the limitations of the available computer and the resulting possible errors in the theoretical values.

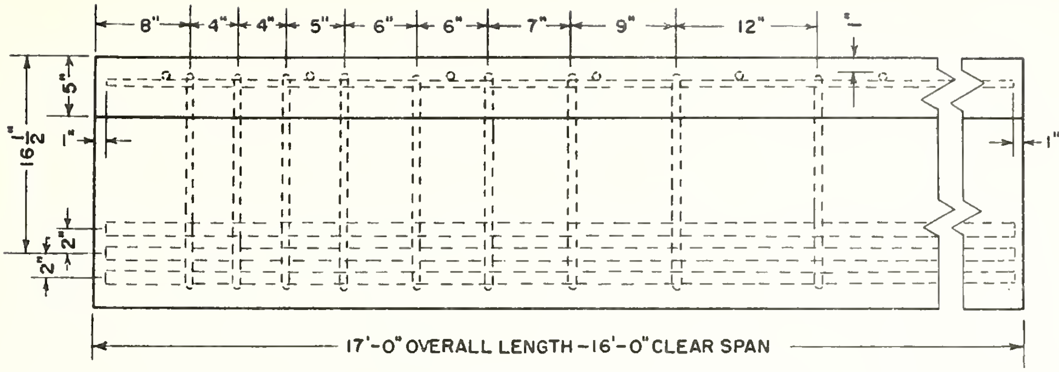
The overall investigation clearly indicates the effect of cover thickness on the fire endurance of reinforced concrete beams. It shows that the assumptions, as given in some fire resistance listings, that fire resistance is independent of cover thickness beyond 1 1/2 in., and that 1 1/2 in. cover is adequate for 4 hr resistance, are both erroneous.

REFERENCES

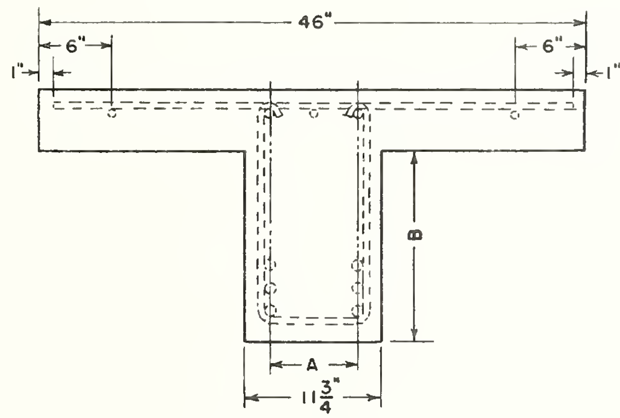
1. "Fire Tests of Concrete Channel Slab Roof Deck Constructions," J. V. Ryan, NBS Report 2747, July 3, 1953. An unpublished report of the National Bureau of Standards to the Department of the Army, Office of the Chief of Engineers.

2. "Theoretical Heat Transfer Scaling Relationships for Fire Endurance of Reinforced Concrete," A. F. Robertson and S. M. Genensky, NBS Report 4854, September 21, 1956. An unpublished report of the National Bureau of Standards, to the Office of Chief of Engineers, Department of the Army and Directorate of Construction, U. S. Air Force.

USCOMM-NBS-DC

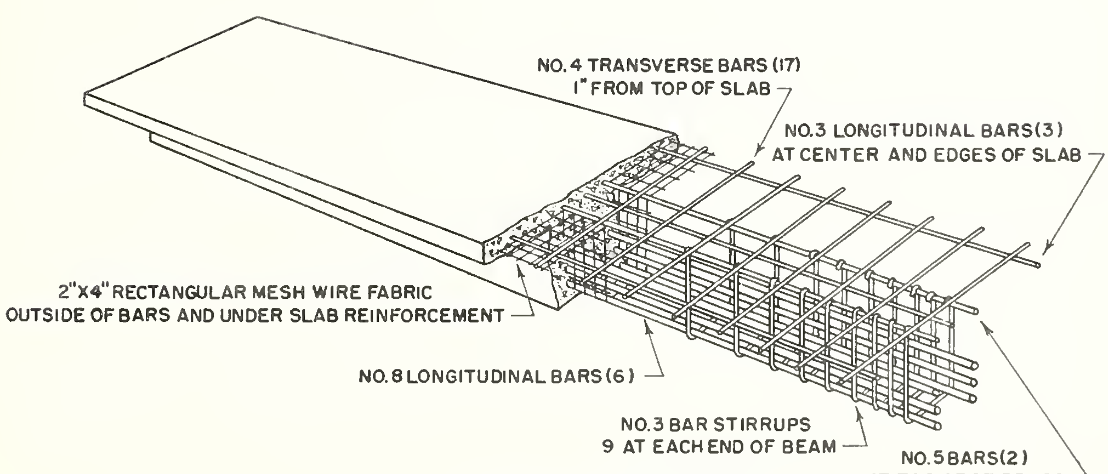


STIRRUP SPACING AND LONGITUDINAL BARS
AT ENDS OF BEAMS



END VIEW OF BEAM

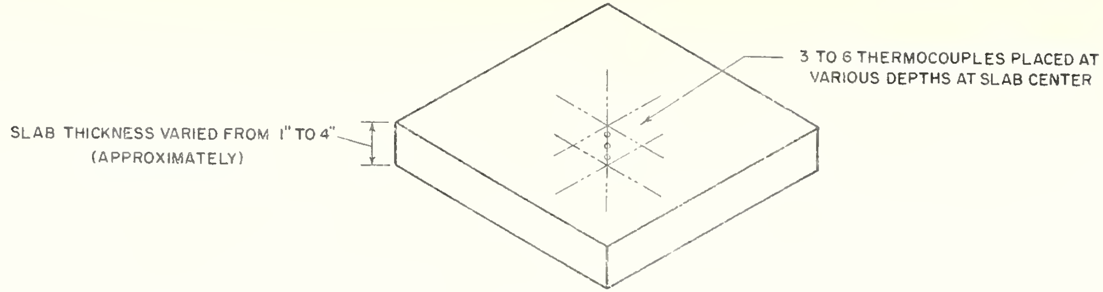
NOTE – DIMENSIONS "A" AND "B" VARY WITH AMOUNT OF PROTECTIVE COVER PROVIDED TO STEEL



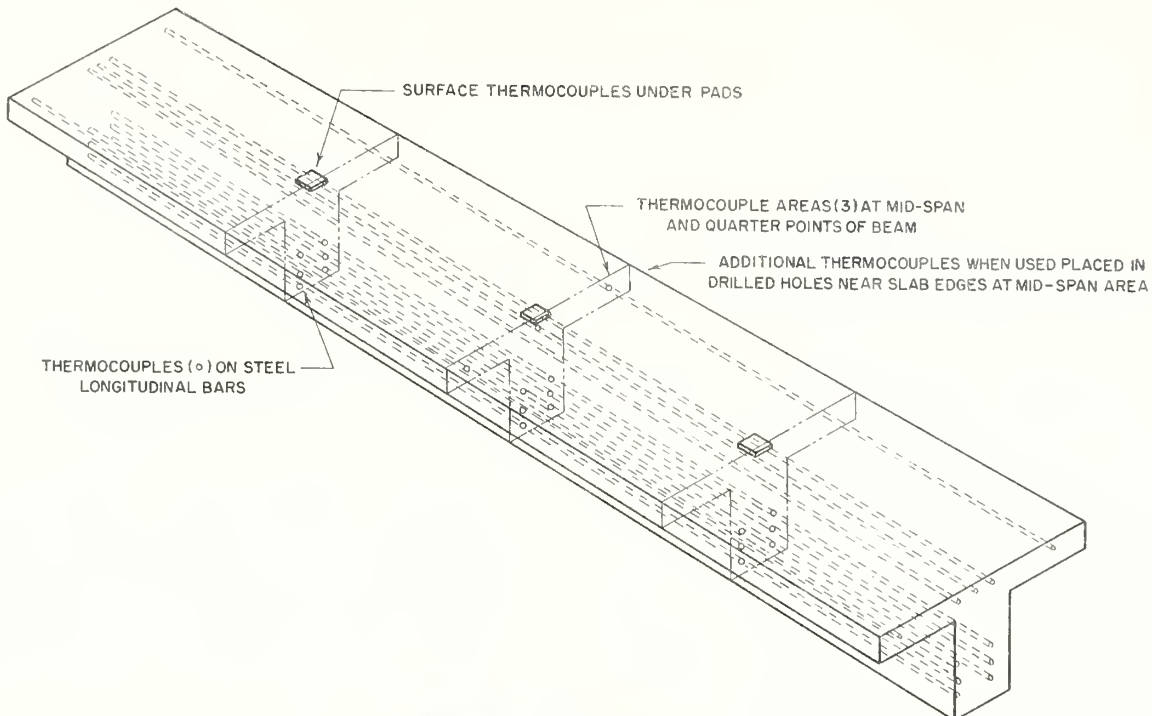
LOCATION OF BARS BY SIZE

NOTE – ALL BARS DEFORMED, OF INTERMEDIATE GRADE STEEL

FIG. 1 – CONSTRUCTION DETAILS OF BEAM SPECIMENS



2'X2' SLAB SPECIMEN



17'-0" BEAM SPECIMEN

FIG. 2 - THERMOCOUPLE LOCATIONS IN SPECIMENS

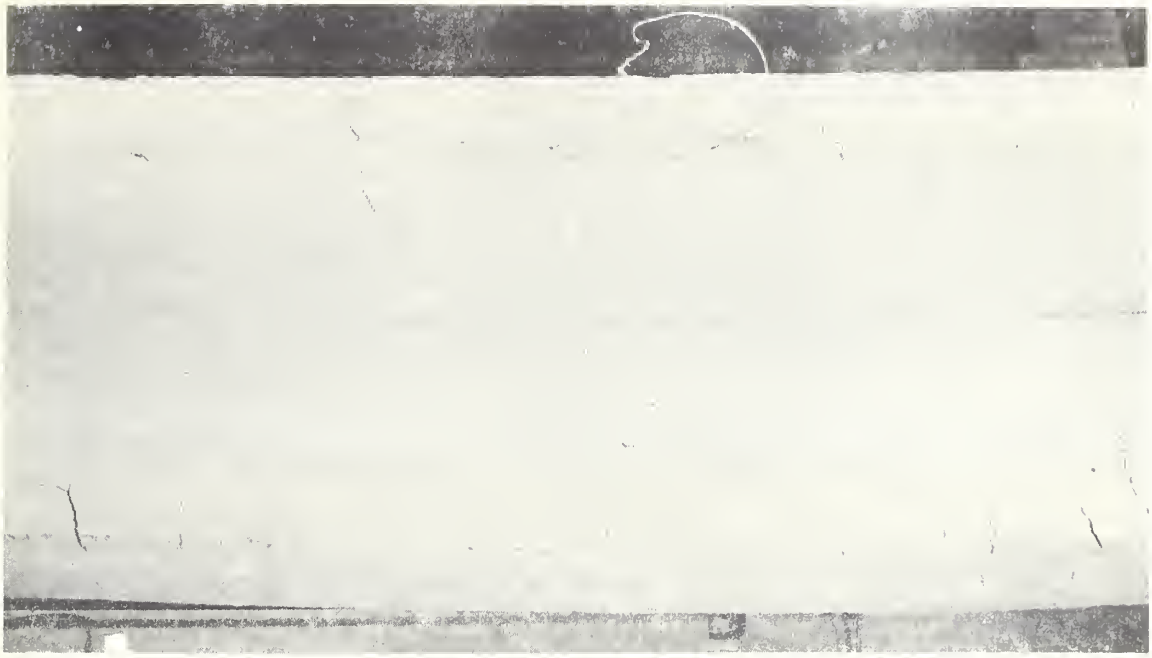


Figure 3. Center portion of beam with 1 in. cover, after test, showing tension cracks but no loss of concrete.

Figure 4. Fairly heavy and extensive sloughing from beam despite presence of wire fabric.

Figure 5. Heavy sloughing and deep cracks to expose reinforcing bars in beam with ½ in. cover and no wire fabric.

Figure 6. Cracking of unexposed surface.

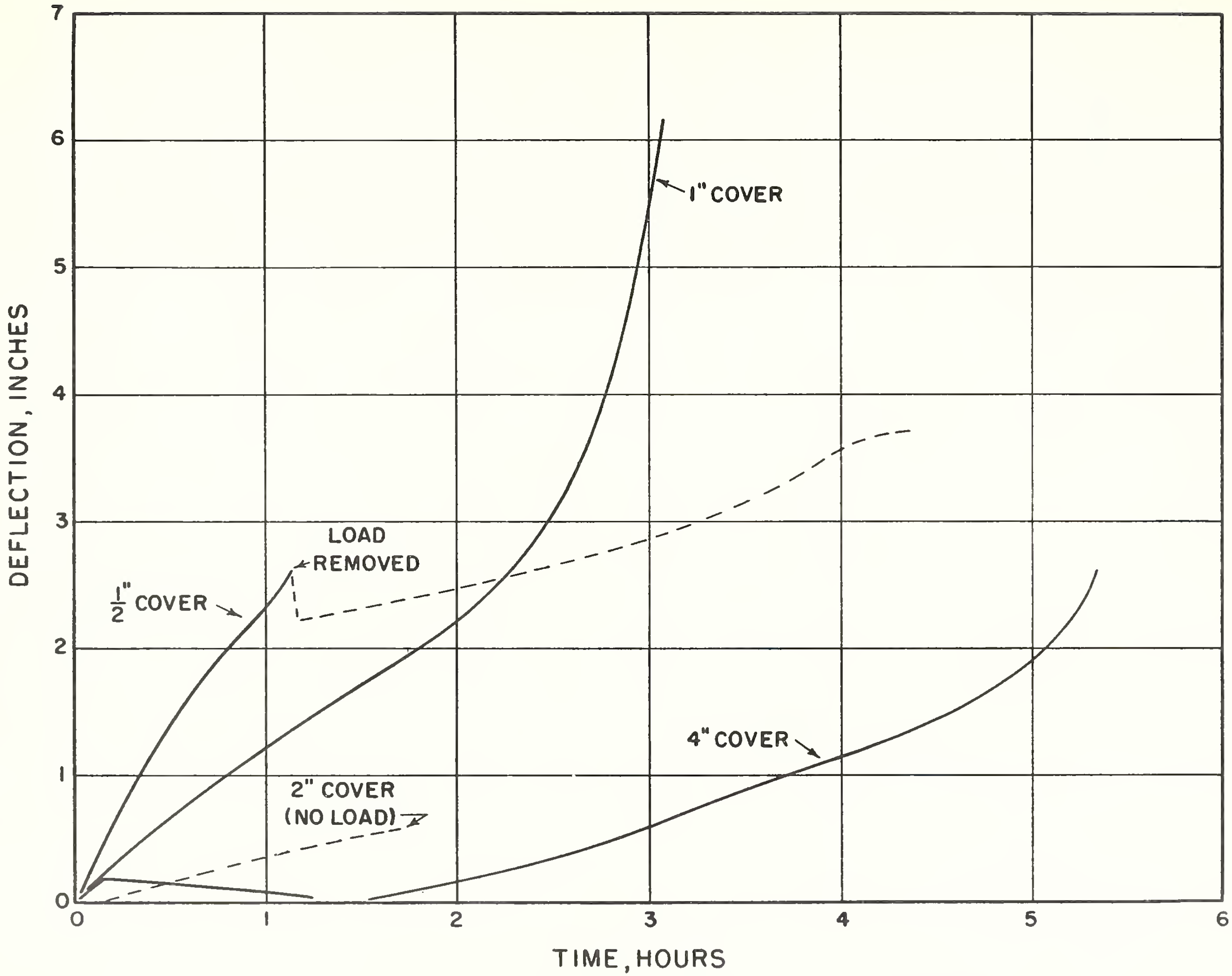


FIG. 7- DEFLECTIONS IN BEAM SPECIMENS

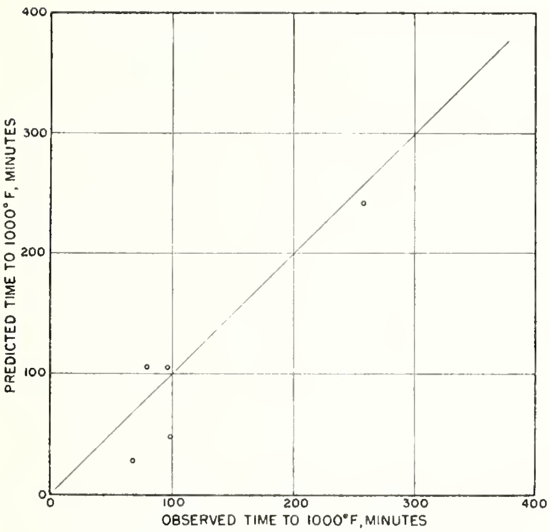


FIG. 8-CORRELATION FOR MAIN BEAM BARS

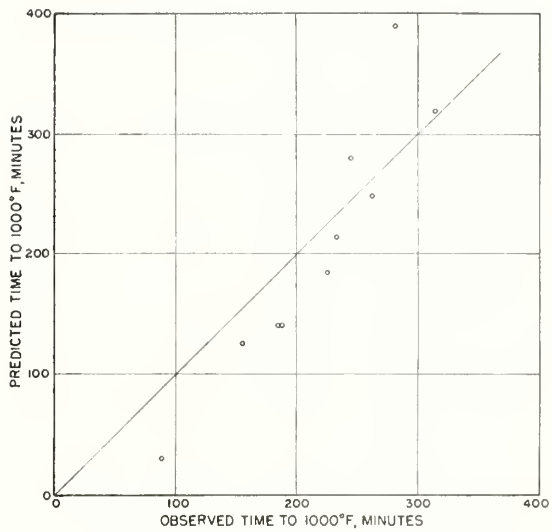


FIG. 9-CORRELATION FOR THERMOCOUPLES IN BEAM SLABS

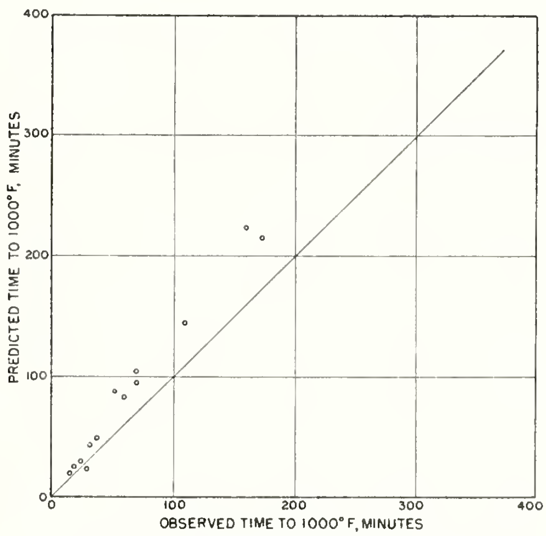


FIG. 10-CORRELATION FOR 2X2 FT. SLABS WITH THERMOCOUPLE PAD

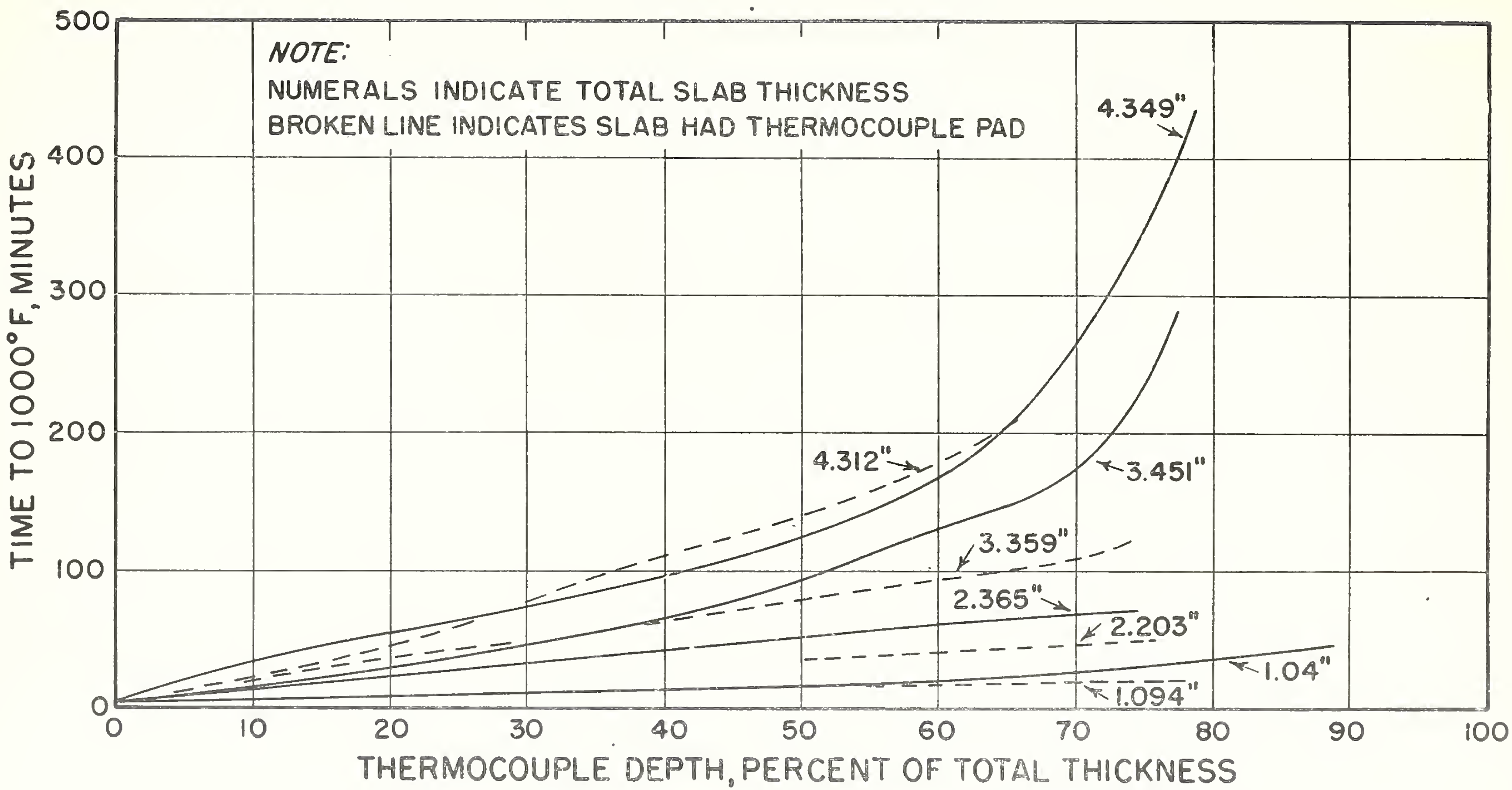


FIG. 11 - EFFECT OF SLAB THICKNESS AND THERMOCOUPLE DEPTH ON TEMPERATURE RISE TO 1000°F

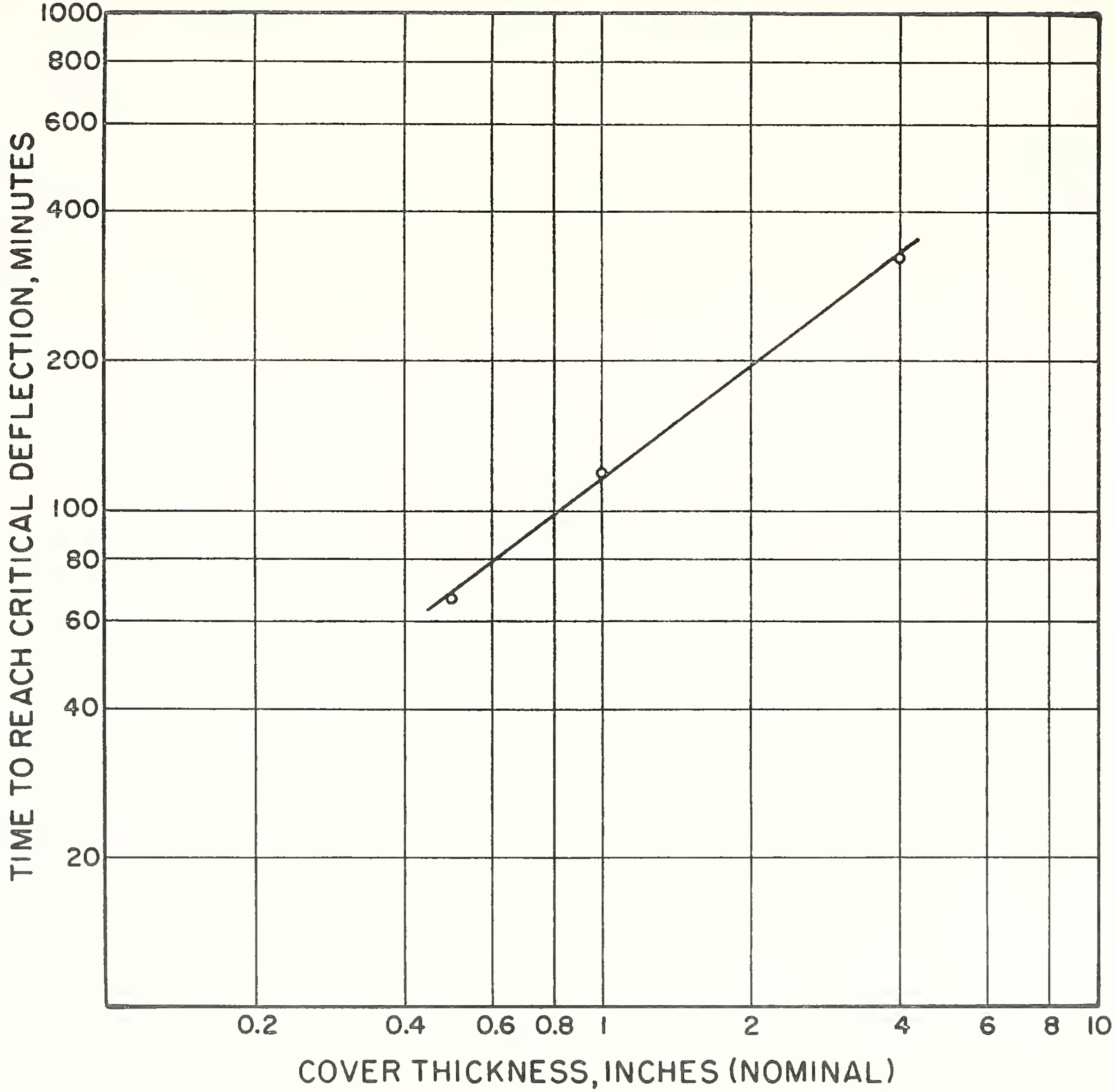


FIG. 12 - CRITICAL DEFLECTION IN BEAMS

U. S. DEPARTMENT OF COMMERCE
Sinclair Weeks, *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 headquarters in Washington, D. C., and its major laboratories in Boulder, Colo., 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 front cover.

WASHINGTON, D. C.

Electricity and Electronics. Resistance and Reactance. Electron Devices. Electrical Instruments. Magnetic Measurements. Dielectrics. Engineering Electronics. Electronic Instrumentation. Electrochemistry.
Optics and Metrology. Photometry and Colorimetry. Optical Instruments. Photographic Technology. Length. Engineering Metrology.
Heat. Temperature Physics. Thermodynamics. Cryogenic Physics. Rheology. Engine Fuels. Free Radicals Research.
Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Neutron Physics. Nuclear Physics. Radioactivity. X-rays. Betatron. Nucleonic Instrumentation. Radiological Equipment.
Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Molecular Structure and Properties of Gases. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.
Mechanics. Sound. Mechanical Instruments. Fluid Mechanics. Engineering Mechanics. Mass and Scale. Capacity, Density, and Fluid Meters. 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.
Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Concreting Materials. Constitution and Microstructure.
Building Technology. Structural Engineering. Fire Protection. Air Conditioning, Heating, and Refrigeration. Floor, Roof, and Wall Coverings. Codes and Safety Standards. Heat Transfer.
Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.
Data Processing Systems. SEAC Engineering Group. Components and Techniques. Digital Circuitry. Digital Systems. Analog Systems. Application Engineering.

• Office of Basic Instrumentation. • Office of Weights and Measures.

BOULDER, COLORADO

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.
Radio Propagation Physics. Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services. Sun-Earth Relationships. VHF Research.
Radio Propagation Engineering. Data Reduction Instrumentation. Modulation Systems. Navigation Systems. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Radio Systems Application Engineering. Radio Meteorology.
Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. High Frequency Impedance Standards. Calibration Center. Microwave Physics. Microwave Circuit Standards.

NBS