NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE **41**

BRIDGE BEARINGS

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE **41**

BRIDGE BEARINGS

RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST:
- BRIDGE DESIGN
- CONSTRUCTION
- GENERAL MAINTENANCE
- RAIL TRANSPORT

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. 1977

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

NCHRP Synthesis 41

Project 20-5 FY '74 (Topic 6-09)
ISBN 0-309-02542-7
L. C. Catalog Card No. 77-10359

Price: $4.80

Notice

The project that is the subject of this report was a part of the National Cooperative Highway Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council, acting in behalf of the National Academy of Sciences. Such approval reflects the Governing Board's judgment that the program concerned is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the National Academy of Sciences, or the program sponsors.

Each report is reviewed and processed according to procedures established and monitored by the Report Review Committee of the National Academy of Sciences. Distribution of the report is approved by the President of the Academy upon satisfactory completion of the review process.

The National Research Council is the principal operating agency of the National Academy of Sciences and the National Academy of Engineering, serving government and other organizations. The Transportation Research Board evolved from the 54-year-old Highway Research Board. The TRB incorporates all former HRB activities but also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society.

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Printed in the United States of America.

PREFACE

There exists a vast storehouse of information relating to nearly every subject of concern to highway administrators and engineers. Much of it resulted from research and much from successful application of the engineering ideas of men faced with problems in their day-to-day work. Because there has been a lack of systematic means for bringing such useful information together and making it available to the entire highway fraternity, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize the useful knowledge from all possible sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series attempts to report on the various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which they are utilized in this fashion will quite logically be tempered by the breadth of the user's knowledge in the particular problem area.

FOREWORD

By Staff
Transportation
Research Board

This synthesis will be of special interest and usefulness to bridge engineers and others seeking information on design, fabrication, construction, and maintenance of bridge bearings. Detailed information is presented on design considerations for various expansion devices.

Administrators, engineers, and researchers are faced continually with many highway problems on which much information already exists either in documented form or in terms of undocumented experience and practice. Unfortunately, this information often is fragmented, scattered, and unevaluated. As a consequence, full information on what has been learned about a problem frequently is not assembled in seeking a solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of synthesizing and reporting on common highway problems. Syntheses from this endeavor constitute an NCHRP report series that collects and assembles the various forms of information into single concise documents pertaining to specific highway problems or sets of closely related problems.

Present procedures for design, fabrication, construction, and maintenance of bridge bearings vary considerably. This report of the Transportation Research Board reviews concepts and performance records for currently used expansion devices such as sliding plates, rollers, rockers, and elastometric pads.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researchers in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

CONTENTS

ACKNOWLEDGMENTS

This synthesis was completed by the Transportation Research Board under the supervision of Paul E. Irick, Assistant Director for Special Projects. The Principal Investigators responsible for conduct of the synthesis were Thomas L. Copas and Herbert A. Pennock, Special Projects Engineers.

Special appreciation is expressed to Arthur L. Elliott, Sacramento, Calif., who was responsible for the collection of data and preparation of the report.

Valuable assistance in the preparation of this synthesis was provided by the Topic Panel, consisting of Frank C. Edmonds, Assistant Engineer of Bridges, Seaboard Coast Line Railroad; George A. Harper, Structural Engineer, Office of Engineering, Federal Highway Administration; Wayne Henneberger, Bridge Engineer, Texas Department of Highways and Public Transportation; Bernard F. Kotalik, Chief Bridge Engineer, Pennsylvania Department of Transportation; Clellon L. Loveall, Assistant Engineer of Structures, Tennessee Department of Transportation; Jerar Nishanian, Structural Research Engineer, Office of Research, Federal Highway Administration; Vernon W. Smith, Assistant State Highway Maintenance Engineer–Structures, Georgia Department of Transportation.

William G. Gunderman, Engineer of Materials and Construction, Transportation Research Board, and Lawrence F. Spaine, Engineer of Design, Transportation Research Board, assisted the Special Projects staff and the Topic Panel.

Information and plans on current practices, as well as old designs, were provided by many highway agencies. Their cooperation and assistance was most helpful.

BRIDGE BEARINGS

SUMMARY

Bridges are not static structures but are continually moving. The movements are caused by expansion and contraction, deflection, earth pressures, and other forces, and usually are accommodated by bearings. An almost endless variety of bearing devices has been used, including sliding plates, small- and large-diameter roller nests, large single rollers, rockers, and elastomeric pads. The current trend in bridge designs is to eliminate bearings and to accommodate the movement within the structure by means such as flexible piers.

In most cases, use of an expansion device is the simplest solution. Unfortunately, such devices often are not given proper consideration in the design stage; yet the success or failure of the entire structure may depend on how well these devices perform.

Selection of a bearing depends on a number of factors, including expected movement and loading. For movements of less than 3 in. (75 mm), elastomeric pads can be used. For movements up to 6 in. (150 mm), large single rollers or small rockers can be used. For greater movements, large rockers or rollers are usually used.

Sliding devices are the simplest form of bridge bearing; the earliest ones were simply steel sliding on steel. A lubricant is sometimes used between the surfaces. However, dirt and corrosion causes these bearings to freeze quickly and fail. Lead sheets between the plates help; however, the lead usually works its way out. Self-lubricated bronze plates that have inserts with a graphite compound work well if they are kept free of dirt and dust. Recently, polytetrafluoroethylene (TFE) sliding on stainless steel has been adopted for use in bridge bearings because of its low coefficient of friction. It also must be protected from dirt and dust.

Rolling devices were developed when the problems with sliding devices became known. Roller nests—several small-diameter rollers tied together—appeared to be an ideal device for expansion movements. When they are new and clean they work well. Because the nests have many small spaces where dirt and moisture can collect, however, they soon jam and turn into a bed of flaked rust. Efforts to seal the nests against dirt and moisture have proven to be impossible. Larger, simpler, and more open single rollers have been designed to alleviate the problems of roller nests. Single rollers 6 in. (150 mm) and larger do perform well, particularly if the bearing detail is open and able to be cleaned by wind action. Segmental rockers are actually sections of large rollers but are lighter and occupy less space than a full roller. Pinned rockers are a modification of the segmental rocker and are probably the most popular rocker design today, especially for long spans and heavy loads.

Linkage devices or pins are used between girders where no moment is to be transmitted. Long compression-tension struts are often used as end bearings for long bridges.

Elastomeric bearing pads come close to being the perfect bridge bearing; they have no moving parts to freeze, nothing to corrode, and have little or no maintenance requirements. They are extremely popular for movements of less than 3 in. (75 mm); many are being used for larger movements. Their success depends on

the quality of the elastomer. Many early failures resulted from poor-quality material. Rigid specifications as to composition, limits on the manner of fabrication, and testing for quality can assure long, satisfactory performance. Neoprene with a durometer hardness of 55 is the most generally used elastomer. Plain pads still are used for very short spans. However, most pads used today are laminated; they consist of alternate layers of elastomer and metal or fabric laminations. Pot bearings use a confined elastomer to carry the load and accommodate rotation. They are combined with a stainless steel plate and TFE to accommodate expansion movements.

Routine maintenance of bridge bearings should be directed toward keeping the bearings clean and free of water, salt, and debris. The maintenance inspector should also look for evidence that the bearing is or is not performing, such as cracks on abutments or piers, bumps at bridge joints, deflection in railings at joints, and rockers tipped too much or out of line. Adequate maintenance and inspection records should be kept.

Corrective procedures for failed bearings depend on the reasons for the failure. Generally, the bearing is replaced with a more satisfactory type. But if the bearing has served its expected life, or nothing better is available, or only a short-time repair is desired, the same type of bearing can be used.

There is and has been a lack of coordination between maintenance and design. Maintenance personnel deal with problems as they find them and solve them to the best of their ability without asking for help from anyone. The designer must take the initiative and ask maintenance employees about bearing problems.

Some of the conclusions and recommendations of this synthesis include:

- A bridge should be designed with as few movable bearings as possible. Where allowable, movements should be absorbed within the structure.
- Bridge bearings are working, active mechanisms and should be designed and maintained as such.
- Bearings should be designed to require a minimum of maintenance.
- Bearings do fail; wherever possible, provisions should be made so that the bridge may be jacked up and the bearings adjusted or replaced.
- Material quality is of the utmost importance in elastomeric bearings. Quality must be carefully specified. In addition, an adequate inspection and testing program should be in operation.
- Inspection of bridge bearings should be an important part of a regular bridge inspection program.

CHAPTER ONE

INTRODUCTION

In contrast to other working mechanisms, bridges are generally regarded as static structures incapable of movement (unless designed to be opened). This synthesis examines what are generally regarded as fixed bridges. However, anyone concerned with maintenance of bridges soon discovers that all bridges are continually moving. Expansion and contraction caused by temperature changes, deflection caused by loads, movement of the adjacent earth, pressures of ice and stream flow, and centrifugal and longitudinal forces of vehicles all combine to produce motion in a bridge. Such movement is deceptively slow; however, the forces involved are tremendous. If the ability to move is not built into the bridge, it pushes and tears at its supports until it achieves the freedom of movement it requires.

Movement is usually accommodated by bearings; however, because bridge bearings are often sources of trouble, many bridges are designed so that the entire structure takes care of movement without bearings. This is done by making bridge piers flexible, using radial expansion if the bridge is on a curve, allowing for movement in the abutments, and being sure the approach pavement is not so rigid that the bridge is locked into place and not allowed to expand and contract as temperatures dictate. When these methods can not be used, however, expansion details must be provided to allow the bridge free movement.

To provide this freedom of movement, an almost endless variety of bearing devices has been used on and under bridges. Some worked well; others did not. Some seemingly good designs have failed for reasons not immediately apparent. Maintenance has always been a crucial factor. Because most bridges have bearings and because over the years there has been a continual search for something better, this synthesis is intended to outline the broad range of bearing problems and solutions for all bridge designers and to assist beginning designers in bridge design.

HISTORY

Ever since the first builder laid a log across a stream and observed that there was longitudinal movement during the length of a day and even more pronounced movement from winter to summer, engineers have been trying to devise foolproof expansion devices for bridges. Early devices consisted of flat surfaces on which the members could slide. The surfaces were greased and covered with tallow to make sliding easier. But the grease attracted and held dust and dirt, which increased the friction and froze * the joint. The sliding surfaces corroded and galled under pressure, inevitably freezing up and forcing some other part of the bridge to fail in order to allow movement.

There have been many attempts to improve the concept of sliding plates because of its basic simplicity. Different metals have been used to reduce galling. Other lubricants have been introduced, such as graphite and sophisticated greases. Polytetrafluoroethylene (TFE or PTFE; also trademarked by DuPont as Teflon) sliding on stainless steel gives the lowest mechanically available coefficient of friction and in recent years has been adopted for bridge bearings. Some of these devices perform better than others; however, all are vulnerable to dirt and require regular maintenance.

Following the development of sliding plates, various types of roller nests came into general use. The first roller nests used rollers with a small diameter [1.5 to 2 in. (38 to 50 mm)]. This seemed a logical solution; small rollers worked well while new and clean. However, because the expansion bearings of a bridge are largely neglected after completion of construction, the rollers soon became dirty, collected moisture, and rusted.

The next improvement was to enlarge the rollers. It was reasoned that if small rollers collected dirt and were hard to clean, bigger rollers would (a) provide better access, (b) be easier to clean, and (c) have a tendency to roll over accumulated dirt. It was common to specify a minimum 6-in. (150-mm) diameter for rollers. Many older design specifications state that bearings should be kept clean, enclosed in a dust-tight canopy, yet arranged so that the bearings could not retain water. Design specifications are usually not made available to maintenance employees, however, and these bearings also failed when not maintained.

With larger, single rollers, 9 to 15 in. in diameter (230 to 380 mm), it seemed that the pressures would be such that any dirt in the way would be crushed and that with larger, more open rollers, dirt would be blown or washed away by the weather making the roller easier to maintain. These were also neglected, however, and moisture crept into the tight area at the tops and bottoms of the rollers, corroding the metal and developing flat spots on the rollers. Temporary repairs could be made by jacking up the bridge and rotating the rollers a quarter turn to bring new circular sections into the bearing areas.

The next natural development was the rocker, which was actually only a segment of a large roller. Rockers were made with two arcs (one above and one below) on which the bearing plates rolled. A rocker could also be a single arc with the other end fastened to the superstructure by a pin or cylindrical socket. This device is still used in long bridges to take care of large movements.

Also in the manner of roller nests, groups of four or more rockers were often linked together with tie bars on each end to keep them separated and in position. This complicated the bearing design and provided many small

* "Freeze," "froze," and "freezing" when applied to bearings indicate that all mechanical movement has been prevented by corrosion, mechanical binding, intrusion of dirt, or other interference to the point that the bearing is inoperable or held in a rigid condition.

places in which water and dirt could collect and damage the bearing.

Extremely long spans with movements greater than 1 ft (0.3 m) often include eyebars or rocker arms to support the load and still allow large movements. The arms may be suspended from above or anchored below in deep wells in the piers. Longer arms are used to minimize the change in elevation of the deck surface. Working on the arc of a circle, the deck moves up and down as the pinned rocker arm rocks back and forth.

Some large bridges use rack and pinion arrangements. Two geared racks are provided, one on the pier and another directly above it on the superstructure. A large pinion gear is in between, fastened to the roller shaft that rolls back and forth between the two racks to keep the rollers in position.

All of these devices work initially. Their long-term efficiency and success depend largely on the degree of maintenance that they receive. Maintenance is difficult and onerous. Engineers have recognized that so long as bridges require constant attention to make them function, these structures are in danger of developing a failure because of inattention. They have long sought some foolproof expansion device requiring little or no maintenance.

With the development of synthetic rubber during World War II, the elastomeric pad came into use. Practically inert and unaffected by weather, it had no moving parts in the usual sense, yet it provided support and accommodated movements of several inches. Before this device could be perfected, however, many failures resulted from poor-quality material. Improvements were made and are still being made. Today the elastomeric bearing pad is the best expansion bearing for moderate movement that has been developed in the progression from sliding plates through the various types of rolling devices.

TABLE 1

CLASSIFICATION OF BRIDGE BEARINGS BY FUNCTION

1. Sliding plates
   a. Steel on steel
   b. Steel on bronze
   c. Lead sheets between steel plates
   d. Bronze plates with graphite inserts
   e. TFE sliding on stainless steel
      (1) Steel plates faced with TFE
      (2) Fabric pads faced with TFE
      (3) Elastomeric pads faced with TFE
   f. Felt, oil and graphite, tar paper

2. Rolling devices
   a. Roller nests
   b. Single rollers
   c. Segmental rockers
   d. Pinned rockers
   e. Rack and pinions
   f. Steel balls

3. Linkage or eyebar devices
   a. Simple link hangers
   b. Compression-tension struts
   c. Pin connections permitting rotation but no horizontal movement

4. Elastomeric devices
   a. Simple elastomeric pads (or combined with TFE)
   b. Stacked pads with intermediate restraining layers
   c. Circular restrained or "pot" bearings

5. Other devices
   a. Hydraulic cylinders or dash-pots
   b. Floating arrangements
   c. Spherical bearings

6. Structural flexibility
   a. Timber structures
   b. Tall flexible piers
   c. Curved bridge designs

CURRENT TRENDS

There is a definite trend among designers to avoid the use of bearings wherever possible. A variety of structural innovations is available that eliminates the necessity for bearings.

Some long bridges are designed with tall, flexible piers capable of bending with temperature changes in the superstructure, thus eliminating the need for expansion devices anywhere on the bridge except at the abutments. Thus, the entire movement must be accommodated there. This requires a more complicated device at the abutments to accommodate large movements; however it is a better solution than having several expansion joints throughout the span. Avoiding expansion joints in the spans results in a more rigid bridge. The movement can be handled more efficiently at the abutments where it is also easier to provide the emergency restraint necessary for earthquake safety.

Long, looping ramp structures can be designed so that the expansion is handled by allowing the span to "breathe" in and out along the curve as the superstructure shortens and lengthens with temperature changes. This, too, requires flexibility in the piers so that bending can take place.

Some long bridges have been designed with a continuous superstructure but with a provision for expansion at the top of each pier. Thus, the entire superstructure acts as a unit but slides back and forth on top of the piers, carrying the total expansion movement to the abutments. This system works when well maintained, but as soon as a bearing freezes on an inflexible pier, cracks, spalls, and other problems result.

Spans less than approximately 40 ft (12 m) need not be designed to allow for end rotation caused by deflection in the span. When the span deflects, it causes a flat bearing to shift the load to the front edge of the bearing. In general, spans greater than 40 ft must have some provision to allow for end rotation. Properly designed rollers, rockers, and elastomeric pads should handle this rotation without difficulty. Sliding plates of various materials are sometimes curved in a vertical plane to allow rotation without overloading the front edge. Single rollers and rockers can accommodate rotation easily, but roller nests are subject to the same faults that flat plates are (i.e., rotation forcing the entire load onto the front roller).

Bridge bearings can not be hermetically sealed because of the basic necessity for movement of one part in relation to another. The best solution, therefore, seems to be to seek designs that are self-cleaning, do not require careful attention, and have a chance of surviving with only perfunctory maintenance.

APPLICATION

Bearing devices must carry a vertical load and at times a horizontal load. Some must also accommodate horizontal movement, or rotation, or both. The vertical load is usually positive (compression) but may be negative (tension) in some cases. There must be provision for lateral restraint against wind, centrifugal force, and earthquake loads so that the superstructure does not slide obliquely off the bearing. The device must be capable of accommodating the greatest horizontal movement likely to occur plus additional room for extraordinary movements caused by earthquakes and collisions. In earthquake situations, additional restraint must be provided to keep the joint from separating and dropping the span.

The bearing device should function satisfactorily with a minimum of maintenance or even in a state of neglect. In addition, it should also be simple and economical, not occupy a great deal of space and, if visible, not be a disturbing influence on the appearance of the structure. Bearing types classified by the manner in which the bearing functions are given in Table 1. Materials that have been used in bridge bearings are given in Table 2.

CONVENTIONAL DESIGN, FABRICATION, CONSTRUCTION, AND MAINTENANCE

After some experimentation, conventional designs were developed and used extensively in a wide variety of installations. Many of these designs have not necessarily been the most successful but, rather, the most widely used. Thus, early in this century, there were a great many roller nests used under steel trusses. When it became obvious that roller nests had serious faults, other types were adopted.

Pinned rockers for steel trusses and large-girder spans are used widely. Cast-steel, double-segmented rockers in which the radii of the faces are larger than one-half the depth of the rocker have been used for many longer steel-stringer and girder spans (Fig. 1), even though these rockers raise the span slightly as they move. Pins and short

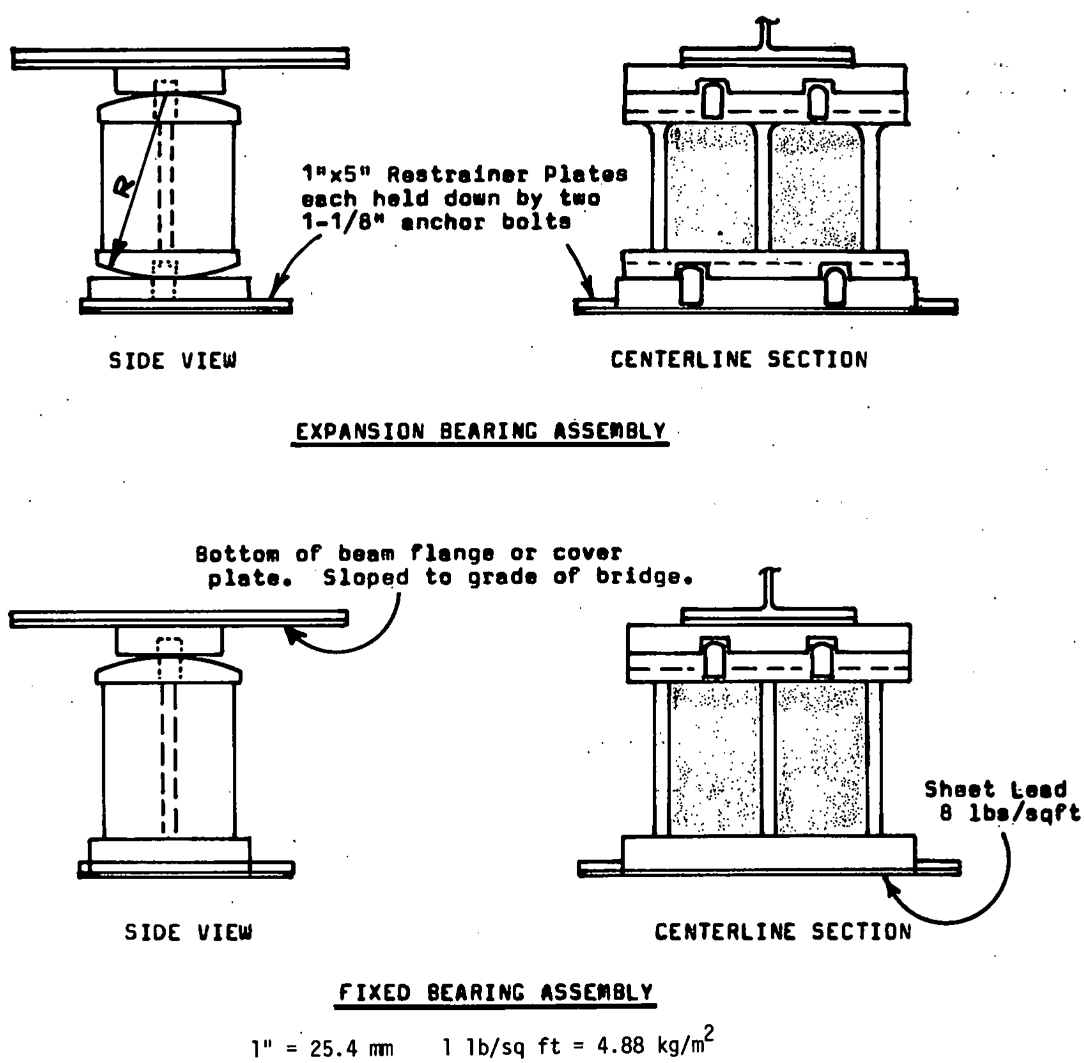


Figure 1. Modern rocker bearings for long steel girders (1975).

TABLE 2

MATERIALS USED IN BRIDGE BEARINGS

1. Steel
   a. Plates
   b. Cylinders, tubes, rollers, and balls
   c. Structural members, cable links, and restrainers
2. Bronze and brass
   a. Sliding plates
   b. Bushings
3. Synthetic materials and natural rubber
   a. TFE sliding devices
   b. Elastomeric pads
   c. Fabric pads (e.g. Fabreeka), canvas and red lead, felt, tar paper
4. Timber and wood
5. Lubricants
   a. Graphite
   b. Greases, oils, silicones
   c. Tallow, goose grease, and bear grease

hangers are often found in steel-girder bridges. The elastomeric pad is widely used on both steel and concrete bridges where the movements do not exceed approximately 2 to 3 in. (50 to 75 mm). Neoprene pot bearings have been used widely in Europe for long, heavy spans where some rotation may be experienced in several planes.

Fabrication of these devices has become a standard structural item. Even the old roller nests seem to have a standard form that was frequently used. Some items are proprietary (e.g., bronze plates trepanned and filled with graphite, and porous bronze filled with a lubricant). The widespread use of elastomeric pads has not been without problems. A high-quality fabrication material is essential but, because elastomeric material is a compounded mixture, it can be adulterated easily and the quality destroyed. Elastomeric pads received many early setbacks because of unscrupulously poor quality. In construction, the successful use of the pads depends on correct installation and uniform loading and support for the pads. There have been costly difficulties because concrete was not carefully placed around the pads. For the most part, elastomeric pads require little maintenance. This is in marked contrast to almost every other expansion device, which depends on persistent maintenance for continued performance.

CHAPTER TWO

GENERAL DESIGN CONSIDERATIONS

SELECTION AND PHYSICAL REQUIREMENTS

Selection of Bearing Type

The selection of an expansion device obviously depends on a number of factors, including the anticipated amount of movement and loading. In the past, when no bearing type worked satisfactorily, designers often tried new and innovative ideas in an attempt to develop a more successful device. At the risk of overstatement, it would seem that every possible mechanical contrivance for handling structure movement has been tried. The introduction of the elastomeric pad revolutionized bridge bearing design. It would now seem that the possibility for future improvement lies in the field of better use of elastomeric materials.

The designer today has several choices and a number of proven systems from which to select. For expansion movements from 2 to 3 in. (50 to 75 mm), the elastomeric pad can be used on all types of bridges. For movements up to 6 in. (150 mm), single rollers 6 to 10 in. (150 to 250 mm) in diameter and small rockers may be used. When movement exceeds 6 in. and may be as much as several feet (or approximately a metre), large rockers, connecting links, long compression arms, or rollers with gear racks are chosen.

The bearing selection process can be summarized as follows:

1. In designing a bridge bearing, select the type of unit that best meets the design requirements and requires the least maintenance.
2. For good performance, design a unit that has large components that do not trap dirt and that either tend to clean themselves by wind action or may be easily cleaned by minimal maintenance attention. Insofar as possible, the bearing should be designed to facilitate inspection.
3. Specify the highest quality in the materials of whatever unit is selected.
4. Even though a bearing is designed to be maintenance-free, its condition should be checked periodically.

Anchorage Requirements

The necessity for anchoragé varies with the type of bearing and the structural need of the bridge at that point. Cantilever anchorages may be massive. Bearings with only occasional small uplift may have only anchor bolts. Earthquake locations may require tie-downs or hold-backs that allow some movement but restrain any extreme or violent movement.

Although theoretically a rolling device should not impart any horizontal thrust to the substructure, the chance that the roller may jam or freeze would dictate that the substructure and the anchorage devices should be capable of withstanding the horizontal thrust of that portion of the bridge if the rollers should freeze. Even though elastomeric bearings do not freeze in the sense that a mechanical bearing does, they do impart some horizontal thrust. This factor should be considered in the design.

There have been cases in which no anchorage was provided and the relative movement of pier and superstructure caused the bearing plate (even with a curved bearing surface) to migrate off the pier and drop to the ground. Thus, it seems that all bearing plates should be securely anchored. Keeper plates should also be provided to direct the motion of any movable element.

Mechanical devices, such as rollers, rockers, gear racks, bronze plates, and pot bearings are all anchored into the substructure. Roller and gear racks run between a pair of upper and lower bearing plates, each of which is either anchored into concrete with embedment bars or straps or bolted down with anchor bolts. Bolting or welding is used to fasten the bearing plates to steel members.

The manner in which base plates are anchored to abutments and piers is quite important. There have been many failures because the anchorage was either inadequate or improperly placed. If the mechanism fails, freezes, or locks up for any reason, all of the stresses built up by the expanding or contracting superstructure are transferred to the support. On a concrete pier, if the base plates have been placed too close to the front edge or if the strap anchors have too little embedment in the concrete, the front of the support is liable to spall, creating a major problem. Such inadequate anchorage results in an expansion condition developing where none was intended.

On the other hand, if the fastenings hold but the support as a whole does not have the stability to resist the force, it may tilt. There have been many piers and abutments pushed or pulled out of plumb because expansion bearings froze. It is not enough merely to think of the masonry plate as being rolled on by the expansion bearing with little or no lateral stress. A large horizontal load may develop. Should something jam, a large lateral load would be applied to the masonry plate. The anchorage and the anchoring straps should be of ample size to handle these stresses. Keeping the plate in position when the concrete is placed is not the anchorage strap's only function.

Years of experience with anchor bolts pulling out, being sheared off, or spalling the concrete have prompted AASHTO to provide a table of minimum requirements for the size and anchorage depths of bolts for various span lengths (AASHTO Bridge Specifications,* Article 1.7.55).

TABLE 3

ALLOWABLE BEARING STRESSES ON MASONRY (AASHTO 1.7.8)

Material	Allowable Bearing Stresses, psi (kPa)
Granite	800 (5 500)
Sandstone and limestone	400 (2 800)
Concrete	
Bridge seats, under hinged rockers and bolsters (not subject to high edge loading by deflecting girder, beam, or truss)	1000 (6 900)
Bridge seats, under bearing plates or nonhinged shoes (subject to high edge loading bythe direct bearing, upon thew plate or shoe, of a deflecting beam or girder) average	700 (4 800)

Note: The foregoing bridge seat unit stresses apply only where the edge of the bridge seat projects at least 3 in. (75 mm) (average) beyond the edge of the shoe or plate. Otherwise, unit stresses permitted will be 75 percent of these amounts.

These are minimums; considering the relative cost of anchor bolts to the rest of the structure, conservatism does not cost much and may save a lot of trouble.

AASHTO Article 1.7.8 gives the allowable bearing stresses under bearing devices on various types of concrete and masonry; these are given in Table 3.

For those cases in which uplift is anticipated, the designer must ensure that the pier is capable of resisting the lifting force. The necessary hold-down force should generally be provided by the dead weight of the pier without reliance on pile uplift. Uplift may sometimes be experienced where none is anticipated. It is not unusual for the end supports of continuous spans to experience uplift when a heavy load is in the interior spans.

The hold-down of a cantilever arm often is a long vertical compression-tension strut pinned at each end. It may be a fabricated member or if it is expected to experience only tension, it may be several eyebars. Smaller uplifting forces can be held by anchor bolts or by cables running down through the bearing assembly to an anchorage. Elastomeric pads are often fabricated with holes or slots in them through which hold-down members run.

Other uplifting forces to be considered are the onslaught of high water and the uplift pressure of ice or driftwood. Large trusses have been lifted off their foundations and carried away by these forces.

Anchorage seats in areas susceptible to earthquakes should be wider than those normally provided. Many bridges have been built with a bearing shelf of 6 to 14 in. (150 to 360 mm). These are inadequate in a moderate earthquake. The Japanese have an arbitrary minimum bearing shelf width of 750 mm (29 in.)

* *Standard Specifications for Highway Bridges*. Amer. Assn. of State Highway and Transportation Officials, 11th ed. (1973) 469 pp. and subsequent *Interim Specifications—Bridges* (1974) 133 pp., (1975) 100 pp. and (1976) 38 pp. These specifications were current at the time of publication and the material herein is based on them; however, the reader should be aware that interim specifications are published annually in the years between the standard specifications, which are republished every four years.

The newest earthquake designs provide for hold-downs and restrainers at abutments and in-span expansion joints. Rockers and rollers are not suited for use in these situations unless they are fitted with auxiliary hold-down links. A wide variety of bolts, cables, short links, eyebars, and compression struts has been used for these emergency hold-down situations. The force that an earthquake restrainer should be capable of withstanding should be 25 percent of the dead load of the bridge that may move from that point.

Capability for Adjustment

There are many circumstances demanding the adjustment of the position of expansion devices. The process is usually not easy. Designers should consider how a bearing device can be adjusted should it become necessary. When a rocker is set during construction, it should be set so that the total travel it experiences can be divided equally by its median position. In other words, on an average day it should stand vertically so that the distance traveled one way for the coldest day equals the distance traveled in the other direction for the warmest day. Bridges are seldom built on average days, however. Thus, the engineer on the job estimates the structure temperature at the time the bearing is set in relation to the total temperature range that the bridge will experience. The proper position of the rocker is calculated and the rocker is set accordingly. Sometimes this estimate is not accurate and it is necessary to make an adjustment.

In some instances, jacking pads are provided to enable bearings to be adjusted. These are two parallel surfaces, one on the pier and one on the superstructure, between which a jack can be placed. The structure can then be lifted minutely to release the rocker so that it can be adjusted. This adjustment procedure is possible only if the rocker is restrained by keeper plates and does not have pintle pins. In the case of pintle pins, the position of the upper and lower plates is also very important and the entire assembly must be set very carefully. Once the concrete has set, any further adjustment presents a major problem, although slotted holes in the masonry plate allow some adjustment. A table on the plans giving bearing settings for various temperatures would be helpful in minimizing adjustments.

Arrangements with jacking pads are also often provided when it is known that an abutment is apt to settle. The bridge can then be jacked up and additional shims added.

In one instance, a bridge was built with one abutment on very poor material. The entire hillside was sliding; even long piles were no solution. A jacking gallery was provided and a plan devised to place hardwood planks under bearings. Periodically, as settlement was observed, the bridge was jacked back up to grade without disturbing traffic and another plank inserted. Some years later when the bridge was replaced by a new road alignment, there were more than 3 ft (0.9 m) of hardwood planks under the bearings of that abutment.

Earthquakes are especially damaging to bearings, and to rocker bearings in particular. It is highly desirable to have jacking pads and jacking space available after an earthquake. In the San Fernando, California, earthquake, one bridge had its rocker bearing turned precisely 90 degrees. It still stood, supporting its load, but faced the wrong way. Its keeper plates had been torn out. It was a simple matter to jack the bridge up, turn the rocker back into position, and then replace the keeper bars. If there had not been space for the jack or nothing to jack against, it would have been a much more extensive problem. Advance thought and planning for the possibility of adjusting an expansion bearing some years after it has been built can save maintenance employees a lot of work, trouble, and cost.

When a prestressed concrete bridge is built with long, simple spans [in the range of 200 to 300 ft (60 to 90 m)] that will be stressed in place (posttensioned), another adjustment problem arises. Upon stressing, the superstructure can shorten as much as 5 in. (125 mm). This is a one-time movement of one end of the span after which it then has only normal temperature movements. Thus, during construction there must be a one-time adjustment. A number of ideas have been used. Because it is a one-time proposition and dirt and maintenance are not a factor, greased plates are often used. Some bridges have had a TFE surface incorporated into the bearing assembly to provide for the one-time slip. TFE has also been used on top of elastomeric pads so that it would be available for the one-time slip and then presumably freeze in place and allow the elastomeric pads to handle the temperature movements thereafter.

Bearings should be arranged with at least a 6-in. (150-mm) clearance between the pier and the soffit of the beams. This clearance is a minimum to allow for cleaning or jacking when bearings must be repaired. When no clearance exists, temporary supports on which to place jacks must be brought up from the ground.

Hydraulic "flat jacks" are an interesting and inexpensive solution to a jacking problem when only a few inches of clearance are available (Fig. 2). A flat jack is a doughnut-shaped double disc of a light-gauge metal. The total thickness is only about 1 in. (25 mm). It may be slipped into a crack and then inflated with a fluid. The metal discs expand and develop a large vertical component. These are generally one-time-use jacks, but with care have been used several times. Epoxy may be used as the fluid and allowed to set in the jack, making a permanent repair.

ECONOMICS

Economy is a function of initial cost and maintenance cost. These two factors have prompted the continual search for better bridge bearings. Virtually all of the innovations of design and the procedures of fabrication have been developed as a result of economic pressures. The type of bearing selected can affect the original cost, the cost of other portions of the structure, and finally the cost of maintaining the structure. Many bearings that have had attractive first costs have proved to be expensive liabilities to maintain. In the long run, the maintenance cost is probably the most important factor.

It is usually a wise investment to make a somewhat larger

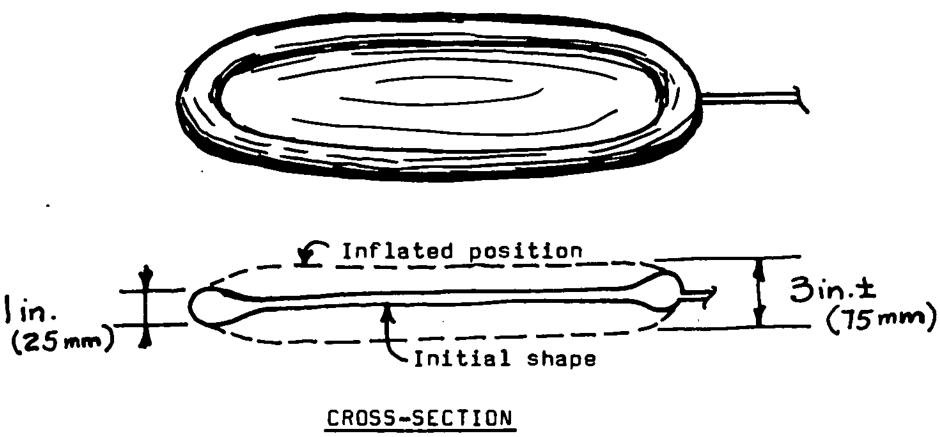


Figure 2. A flat jack.

initial outlay and to be assured of a relatively maintenance-free life. On the other hand, the cost of the bearing may have little relation to its service life. Designers would do well to look beyond the first cost and the ease of the first installation to see what problems are likely to arise in the future and then to develop details that will solve the problems.

Roller nests proved to be an expensive failure after a few years. This led to the use of larger and fewer rollers. Economics led to the welding up of large bearing assemblies rather than casting them in one piece. It also became evident that using a better grade of steel would be a good investment in view of the better service that the resulting bearing gave.

Cost and ease of maintenance were the obvious incentives for the adoption and widespread use of elastomeric bearings. Probably 85 percent of the bridges built in this country are in span ranges that can be accommodated by elastomeric bearing pads. Their lesser cost when compared with steel bearings, their ease of placement, and their normally maintenance-free service life have made them popular.

The production of elastomeric pads in large sheets that could be sawed to shape was also the result of a demand for economy. This represents a great savings over molding each pad to its final size.

ENVIRONMENTAL AND CLIMATIC CONSIDERATIONS

The physical environment should be carefully considered from the outset in the design of a bridge. Every state probably has examples of the wrong bridge in the wrong place—situations resulting in a continual maintenance headache. Steel bridges have been built near salt water when concrete would have been better; the wrong materials have been used in highly corrosive atmospheres near the outfalls of chemical plants; even wrong bridge types have been selected—all resulting in endless maintenance trouble. Bridge bearings are equally vulnerable to local conditions and should be carefully selected.

Steel bearings of all sorts must be protected throughout their design life. They can be galvanized, which is adequate for a period of years, but when the galvanizing finally begins to break down, a regimen of regular painting must be maintained. Corrosion is not a grave concern in large bearing units, but in smaller roller nests, rockers, and rollers, it can result in complete disintegration. Friction bearings with sliding plates of various materials should not be used in dusty or desert conditions unless they are completely sealed off, which is very difficult to accomplish. Blowing sand and dust lodge between the sliding surfaces and grind out the material, increasing the coefficient of friction until the surfaces finally freeze. Chemical environments can also have an adverse effect on certain materials. Ozone deteriorates rubber and may have some long-term effects on other elastomers. Good quality in the elastomer is the best insurance against chemical deterioration. When the elastomer has been excessively adulterated with fillers and other materials, it becomes susceptible to chemical attack and, in a short time, cracks appear on the bulged surfaces of the pads. These soon deepen until the elasticity of the pad is destroyed.

For the most part, temperature stresses and movements generally specified for bridges are quite conservative. Many designers feel that thermal expansion specifications are far too great, resulting in considerable overdesign. In practice, these values never seem to be reached. Efforts have been made to measure the actual expansion and contraction of a completed bridge. The measured movements are far less than what the specifications require be accommodated.

The possible movement of a given span can be calculated to be the same as the expansion and contraction of a solid bar of the same material and length as the bridge for the same expected temperature range. In an actual bridge, however, steel girders are shaded and cooled by a concrete deck; thus, they react slowly to the air temperature changes and may never follow the full temperature excursion made by the air. A concrete bridge provides even better insulation; as a result, reinforcing steel does not experience the temperature peaks at all unless the extreme is of very long duration—a matter of days. When a designer calculates temperature stresses in a short, heavy pier, they can be enormous, dictating the dimensions of the entire pier. Knowing that these temperature extremes will not actually be experienced by the structural members, it is common to use a modified value for the expansion to be designed

TABLE 4

BRIDGE MOVEMENT TO BE PROVIDED FOR TEMPERATURE RANGES (CALIFORNIA DEPT. OF TRANSPORTATION)

Air Temperature Range	Steel	Concrete
Extreme: 120 F (50 C) in certain mountain & desert locations	Rise and fall 60 F (33 C) Movement/unit length 0.00039	Rise and fall 40 F (22 C) Movement/unit length 0.00024
Moderate: 100 F (38 C) interior valleys and mountain sites	Rise and fall 50 F (28 C) Movement/unit length 0.00033	Rise and fall 35 F (19 C) Movement/unit length 0.00021
Mild: 80 F (27 C) Coastal areas	Rise and fall 40 F (22 C) Movement/unit length 0.00026	Rise and fall 30 F (17 C) Movement/unit length 0.00018

for. Table 4 gives values used in California. More research leading to more realistic specifications for linear expansion is long overdue.

The same admonition applies to bearings that applies to all bridges: Know your locale and its environment and design to accommodate it.

MATERIAL CHARACTERISTICS

Components of bridge bearings are usually specified by an AASHTO or ASTM designation that includes material and inspection requirements to assure quality. It is important that the grade of material be specified because the service requirements of masonry and sole plates are such that the harder grades of steel are usually desirable. Should the grade not be specified and an ordinary structural grade used, there is the likelihood that there could be a flattening of the rollers and a cupping of the plates to destroy the effectiveness of the unit.

When special materials are desired for proprietary bearings, these should also be specified. An open specification is often used to avoid mentioning a proprietary name. In this case, specifying quality is important. More than once a slipshod product has been substituted when the designer had in mind a high-quality proprietary product. Normally, however, the manufacturer has a vested interest in the quality of his product and takes care to see that it performs as advertised.

In general, substitutions are to be avoided. Once a designer has determined the most acceptable material, a substitution may result in poor quality and a poor job.

Elastomeric bearings present other problems. The basic elastomer is often purchased from a manufacturer and then combined wtih other materials and molded into pads by a second or even third fabricator. Thus, there is little product responsibility assumed by any of the handlers along the line although each may have altered the quality of the elastomeric material in some manner. One state purchases pads directly from a fabricator and furnishes them to its contractors, thereby minimizing variations in quality from various fabricators.

It is important to have rigid specifications for the composition of the elastomer as well as careful restrictions on the manner of its fabrication. In addition to material specifications, tests should be specified so that the quality can be checked. The test methods of California (Appendix B) and Texas (Appendix C) are examples of tests used to determine the degree of compliance with the specifications. However, a recent study in New Jersey on elastomeric bridge-joint sealers indicates that current specifications and tests for elastomeric materials may not ensure uniform quality and that this can be reflected in the life span of the material.*

FABRICATION AND CONSTRUCTION

The experience and integrity of the fabricator are of great importance to the quality of comparatively small items such as bridge bearings. Compared to the other components of a bridge, bearings are minor in size and often attract fabricators of limited capacity and experience. These incidental parts of a bridge seem suited to the small fabricator; it is not unusual for these items to be contracted out to a local shop. The resulting quality may be better but is more likely to be worse than if some larger, more experienced shop had done the work. The responsibilities of inspection and quality control services then become of vital importance. Where possible, subcontractors and suppliers should be screened to ensure that they are capable of performing satisfactorily.

Welding

The quality of a bearing often depends on fabrication techniques. Many steel bearings currently are fabricated more economically by welding rather than by casting. The welding of a number of comparatively small yet heavy steel sections together to build up a pedestal, a shoe, a hanger, or a pinned bearing can result in severe distortion or in lock-up stresses that can result in a long-term distortion. Experienced welding shops study a weldment and program the welding sequences to minimize distortion. Sometimes straightening is done after welding. Stress-relieving is commonly called for to eliminate locked-in stresses. Machining and boring are done after all welding and stress-relieving has been completed.

* "Preformed Join Sealers for Bridges." Phase II, *HPR Study No. 7731*, New Jersey Dept. of Transportation, forthcoming.

Tolerances

The over-all dimensional tolerances to which bridge bearings are manufactured are generally not too critical. However, good construction practice demands that there be reasonable limits within which the bearing dimensions may vary. Those with mechanically interworking parts must, of course, be carefully machined. Often the match of the riding surface across an expansion joint depends on use of a bridge bearing having the correct dimension. Any noticeable disparity in dimension can create a bump in the roadway.

Galvanizing

Bridge bearing units can be galvanized, which is an added safeguard against corrosion. When galvanizing, if there are any locked-in stresses, the heat of the galvanizing bath may be sufficient to cause severe distortion. This is especially true in lighter sections. Some bridge-deck expansion dams have twisted like corkscrews upon being dipped into a galvanizing bath. As a rule, bearings should be stress-relieved prior to galvanizing. It may be necessary to straighten bearings after galvanizing.

QUALITY CONTROL

Because of the wide dispersion of fabricating plants in which bridge bearings are made, it is generally not feasible to have inspectors in the plant to observe fabrication. Thus, it is necessary to set up sampling, inspection, and testing techniques that can adequately evaluate the degree of compliance with specifications. It is helpful to require that mill pliance with specifications. Reputable manufacturers furnish bona fide mill certificates attesting to the fact that products have been manufactured in accordance with specifications and, further, see to it that their product and practice meet the specifications. Once the reputation and reliability of manufacturers have been established over a long period of time, considerable reliance can be placed on their mill reports. However, all manufacturers are not so conscientious; unexplained mix-ups of certificates being supplied with the wrong lot, as well as other practices, have occurred that result in material that does not meet specifications. If adequate check procedures are not carefully followed, these bad lots of material may not be discovered until they fail in service. Therefore, a rigid procedure of sampling should be followed and random checks regularly performed.

These precautions apply mainly to elastomeric pads. Steel fabricators rarely make mistakes in the quality or grade of steel, although it does happen. These deviations usually show up on mill reports. Nevertheless, there is a responsibility to determine that the correct steel is supplied. It is embarrassing to have a failure and then find that the disparity was plainly evident in the available reports that were not checked.

For many of the materials used in structures, no special allowance is made for the material that is to be consumed by tests. When a piece is clipped off a reinforcing bar, a sample of cement or concrete is taken, or a small section of fencing removed, it is a small bit out of the total and is covered by the normal overruns and underruns. When bearings are to be sampled, however, any unit taken must be replaced. Therefore specifications should define how many samples must be taken and of what kind so that the contractor can furnish extra units for sampling and include the extra cost in the bid. In certain steel applications in which samples are desired, a coupon or oversize extension of a plate can be furnished so that the extra length can be cut off and tested. The important thing to remember is that samples cost money. If several pieces are to be taken for testing, contractors should be warned in advance (in the specifications) so that they can provide (and be paid for) the extra material.

There are tests established for almost every material that is to be used in a structure. Insofar as possible, AASHTO and ASTM tests are the most reliable; they are widely recognized and used in industry. However, some items are not adequately covered by standard tests and special tests must be set up for these materials. Most states have many special test procedures. When the material is to be tested by some special procedure other than a standard test, it should be so noted in the specifications. This alerts all of the suppliers to the standard of excellence they are expected to maintain. When a special problem of quality exists, states should establish their own testing procedures designed to bring out the special features of quality in the product desired.

HANDLING AND PLACEMENT

Bearing Handling and Protection

Bearings, regardless of type, are important devices and must be properly handled prior to installation and carefully maintained after installation.

Machined bearings (plates, cylinders, rockers, pins, etc.) have smooth, finished surfaces. Their efficiency depends on those surfaces being unmarred so that rolling or sliding action is not impeded. Many of them are very heavy, making them hard to handle. The units should, therefore, be crated when shipped to a job. The machined surfaces should be protected with a rust-preventive cover. Heavy grease is sometimes satisfactory. Often one of the plastic materials, such as used for "mothballing" machinery, can be applied. The plastic can be cleaned off after the bearing is in place. Special care should be taken to see that bearings are not nicked or gouged during handling. Bronze plates require even greater care to see that they are not damaged in handling.

Elastomeric pads may seem less fragile, but they too should be handled carefully. If left lying in the area in which they are to be used, they invariably pick up oil, grease, dirt, and cement dust, which is ground into them, destroying surfaces that may be bonded and introducing foreign matter into their action. Elastomeric bearing pads should be kept flat and clean until installation.

Seat Preparation

Although considerable attention has been given to the bridge bearing and the way in which it functions, it is important that it be placed properly if it is to perform well. Providing a firm seat upon the foundation is the first step. In general, seats upon foundations (piers, abutments, footings, etc.) are always placed flat and level. If the bearing is to be given a sloping, cylindrical, or spherical surface, this is applied to the upper face of the bearing plate; the bottom face is always level.

A common requirement for the finish of the concrete surface upon which a bearing device may be placed is that it be finished approximately level at close to the planned elevation. By grinding, building up a pedestal, or other approved means, it can then be brought to a true level plane, which will not vary perceptibly from a straightedge placed on the area in any direction. Some specifications state that the deviation from a flat plane should not exceed ±1/16 in. (±1.5 mm). The finished plane should be within 1/8 in. (3 mm) of the elevation shown on the plans.

These are common requirements that would seem to produce a satisfactory result. However, the pier top is often finished flat and level, and the bearing area is then ground as required. The end result is that the bearing plate is sitting in a dish-shaped area that has been ground in the top of the pier. Water and dirt stand around the bearing, and corrosion is inevitable. The plans and specifications should require that the pier top be slightly domed so that it slopes away from the bearing area once the grinding has been performed. Vertical steps in pier tops between lines of bearings should be avoided because there is a tendency for debris to collect between a set of bearings and the step. This could interfere with the movement of the structure.

Several systems have been used to seat steel base plates on concrete. One method is to use a heavy, red lead paste under the masonry plate. The paste fills in the minute irregularities and provides a solid bearing. A neat cement paste or thin lead sheets have also been used. Pads such as Fabreeka are often used under masonry plates for a slight cushioning, which is sometimes desirable to equalize pressure. To avoid the use of the proprietary name, the following general specification may be used; it also illustrates the nature of the material:

> The preformed fabric pads shall be composed of multiple layers of 8-oz (270-g/m^2) cotton duck impregnated and bound with high-quality natural rubber, or of equivalent and equally suitable materials compressed into resilient pads of uniform thickness. The number of plies shall be such as to produce the specified thickness after compression and vulcanizing. The finished pads shall withstand compression loads of not less than 10,000 psi (69 000 kPa) without extrusion or detrimental reduction in thickness.

Alignment on All Three Axes

Probably the most important factor in the successful operation of any bearing is its alignment. If it is tilted, warped, or miss-set, it can not operate properly.

As has been stated previously, the bottom face should always be level in both directions, even if the bridge is on a grade and the upper faces of the bearing are made parallel with the roadway surface. If appreciable rotation is to be experienced, generally in spans greater than approximately 40 ft (12 m), provision should be made to accommodate it. This may take the form of rollers, pins, curved plate surfaces, or elastomeric bearings or pot bearings.

Although it is possible to tilt a rocker to correspond with what has been estimated as the proper temperature adjustment, it is not possible to precompress or slant an elastomeric bearing. There should be enough movement capability in the bearing so that if it is set near one extreme of its travel (either hot or cold), it will still have enough flexibility to go through the full range of movement it will experience.

The settings of bearings for steel spans are always critical and should be made with great care. The superstructure steel is fabricated in a shop and brought to the field where it is expected to fit down upon the field-set bearings. More than one engineer has had the unfortunate experience of watching the steel span being slowly lowered onto its bearings (sometimes with news cameras in attendance), only to find that the bearing is out of place by an embarrassing amount. Triangulation or casual surveying should not be trusted if direct measurement is possible. A steel tape checked for accuracy (or perhaps the same tape used in the steel shop) should be stretched between the supports and the bearings located as accurately as possible.

CHAPTER THREE

SLIDING DEVICES

STEEL ON STEEL

The earliest expansion bearings were simply steel sliding on steel (Figs. 3 and 4). The mating faces were planed smooth (always placed so that the planer marks are parallel to the direction of movement) and frequently oil, grease, or graphite was placed between the surfaces to keep them free to move. Dirt and corrosion usually took over and the plates froze together. This type of bearing is still used for short spans (Fig. 5).

One of the plates was then made considerably smaller than the other [e.g., a 2-in. × 2-in. (50-mm × 50-mm) bar with a slightly rounded face sliding on a larger steel plate] (Fig. 6). The theory was that if the contact area was small, the forces would overcome the freezing forces. However, in time the smaller bar, using dirt as an abrasive, wore a groove in the base plate and often it too froze.

LEAD SHEETS BETWEEN STEEL PLATES

If the movement is very small, a few states use a lead sheet to separate the two steel surfaces and keep them from freezing together when they corrode. The lead sheet is usually about ⅛ in. (3 mm) thick or 7 lb/ft^2 (34 kg/m^2). The system fails if the movement is great; thus, this type of bearing is usually limited to spans less than 40 ft (12 m) (Fig. 7). Because the lead often works its way out, this type of bearing is not used frequently.

STEEL-ON-BRONZE PLATES OR PAIRS OF BRONZE PLATES

Because steel plates tended to freeze together with rust, the next improvement was to use a material for one of the plates that would not corrode. Bronze plates were used with steel plates; pairs of bronze plates were also tried. As in other designs, dirt worked its way in between the plates, the surfaces were galled, and a mechanical locking of the plates took place. Surface lubricants helped but would not stay in place.

ASBESTOS SHEET PACKING BETWEEN METAL PLATES

Graphite-impregnated asbestos sheeting 1/16 in. (1.5 mm) thick is sometimes used between metal plates to provide for limited movement. Normal requirements are that it deform not more than 16 percent under a 10,000-psi (69 000-kPa) load, that it not lose more than 25 percent upon ignition, and that when tested between planed bronze plates at 700 psi (4 900 kPa), it should have a static coefficient of friction of not less than 0.4 after one hundred ¼-in. (6-mm) movements. Use of this bearing should be limited to spans under 40 ft (12 m).

SELF-LUBRICATING BRONZE BEARINGS

To maintain a graphite lubricant between bearing plates regardless of wear, a proprietary bearing called Lubrite was developed in which portions of the face of a bronze bearing

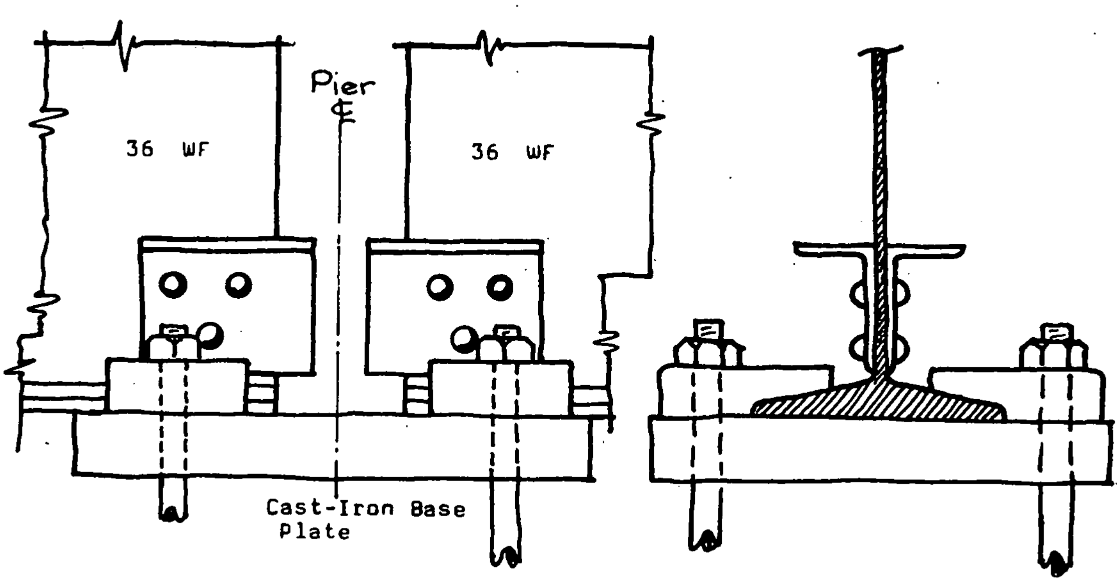


Figure 3. Clip-angle expansion detail (1929).

plate were trepanned out and replaced with a graphite compound inserted under high pressure. The bearings are made in many different forms and some of them have been used on bridges. They come as flat plates (Fig. 8), as plates with one face cut to a radius (Figs. 9 and 10), as cylinders for shaft bushings, as half-cylinders for rockers, and as large self-lubricated bearing washers.

They may be made with practically any bearing metal. With the graphite ever present in the bearing area, the surfaces are continuously lubricated. The manufacturers claim that their materials are corrosion resistant and that their bearings never require any kind of maintenance. This can be true if the bearings are used where they can be protected and kept free of dirt and abrasive dusts, which collect in between the surfaces and increase the friction and wear. One state has experienced corrosion of galvanized-steel bearing plates after several years at some locations.

For ordinary girder bearings, self-lubricating bronze bearings are placed between the masonry (lower) plate and the sole (upper) plate. The bronze plate is secured either to the lower plate with the lubricated surface facing up to bear against the underside of the sole plate, or to the sole plate with the lubricated surface against the masonry plate. The plate facing the lubricated surface must have a machined finish of at least 125 μ in. (3.175 μ m) root mean square (rms), but no other special preparation is necessary. If rotation is anticipated, one face of the bronze plate is machined to a radius; often both faces of the plate are lubricated. An alternate design could have a rocker or pin joint on top of the upper plate to handle the rotation and the bronze bearing would be a flat plate. Self-lubricating bronze bearings can also be used as bushings around rotating pins in pedestal bearings or rockers, or around the pins of a hanger detail. The coefficient of friction is claimed to be between 0.032 and 0.090.

Bronze and copper-alloy sliding plates must be chamfered at the edges and protected from dirt accumulation. These are obvious requirements because sharp edges can gouge the mating plate and dirt lodging between the sliding plates can either grind and roughen the surface or cause the joint to freeze and lock up.

The following is a typical specification avoiding the use of a proprietary name:

> Self-lubricating bearing plates shall be an article of standard production by an established manufacturer of such equipment. They shall be provided with trepanned recesses (not grooves) that shall be filled with a lubricating compound capable of withstanding the atmospheric ele-

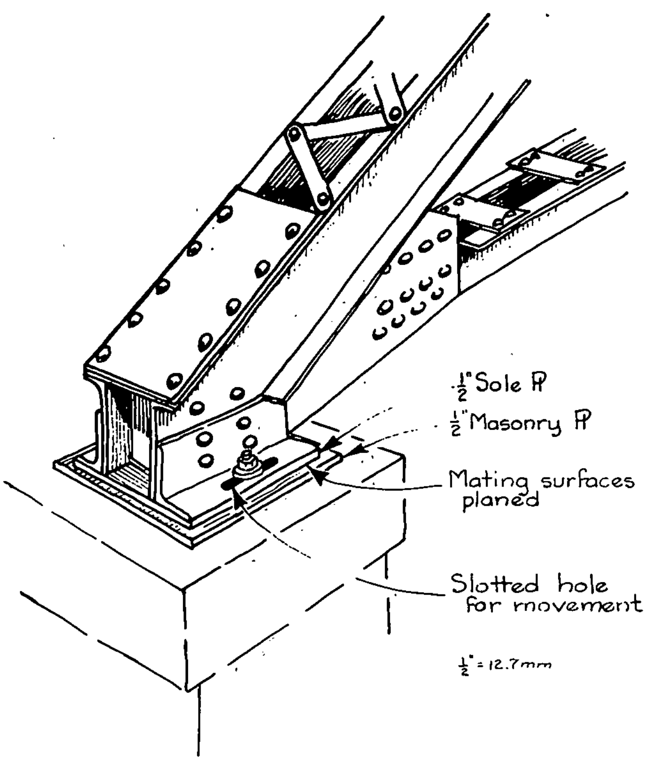


Figure 4. Expansion bearing for a 50-ft (15-m) pony truss (archaic).

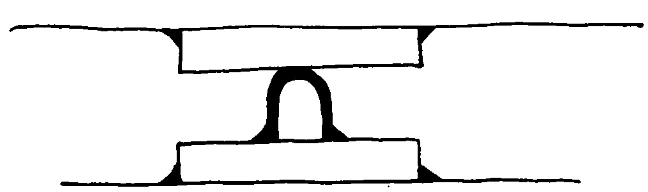


Figure 6. Steel-lug bearing. Works by brute force on short spans; prone to freeze and lock up.

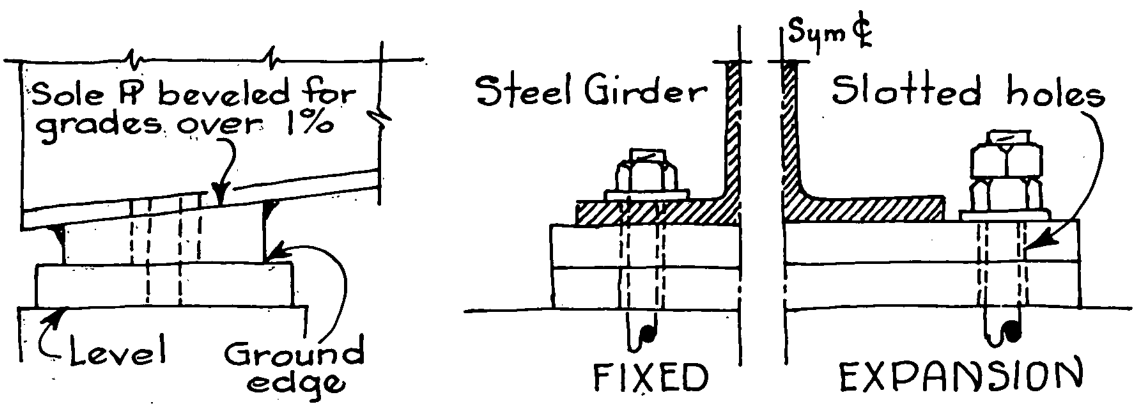


Figure 5. Sliding-plate bearing for short spans.

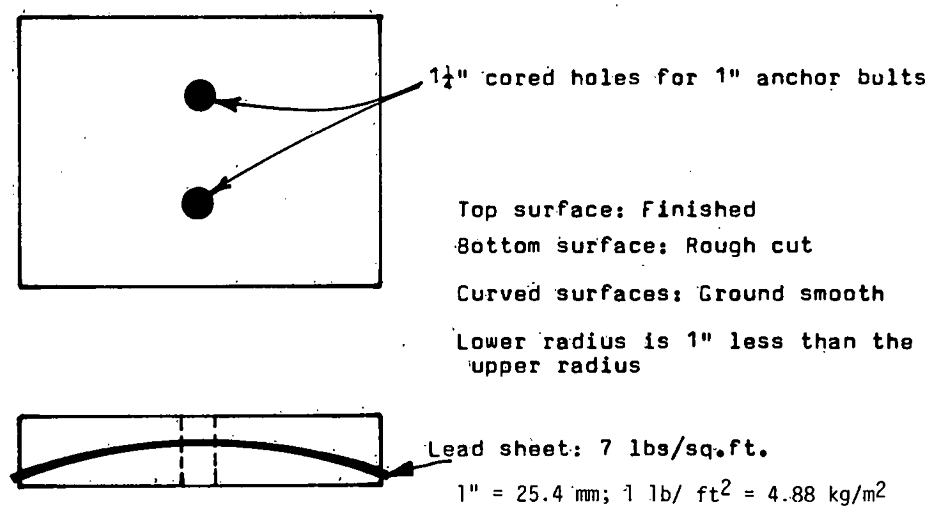


Figure 7. Curved cast-steel plate bearing with lead sheet.

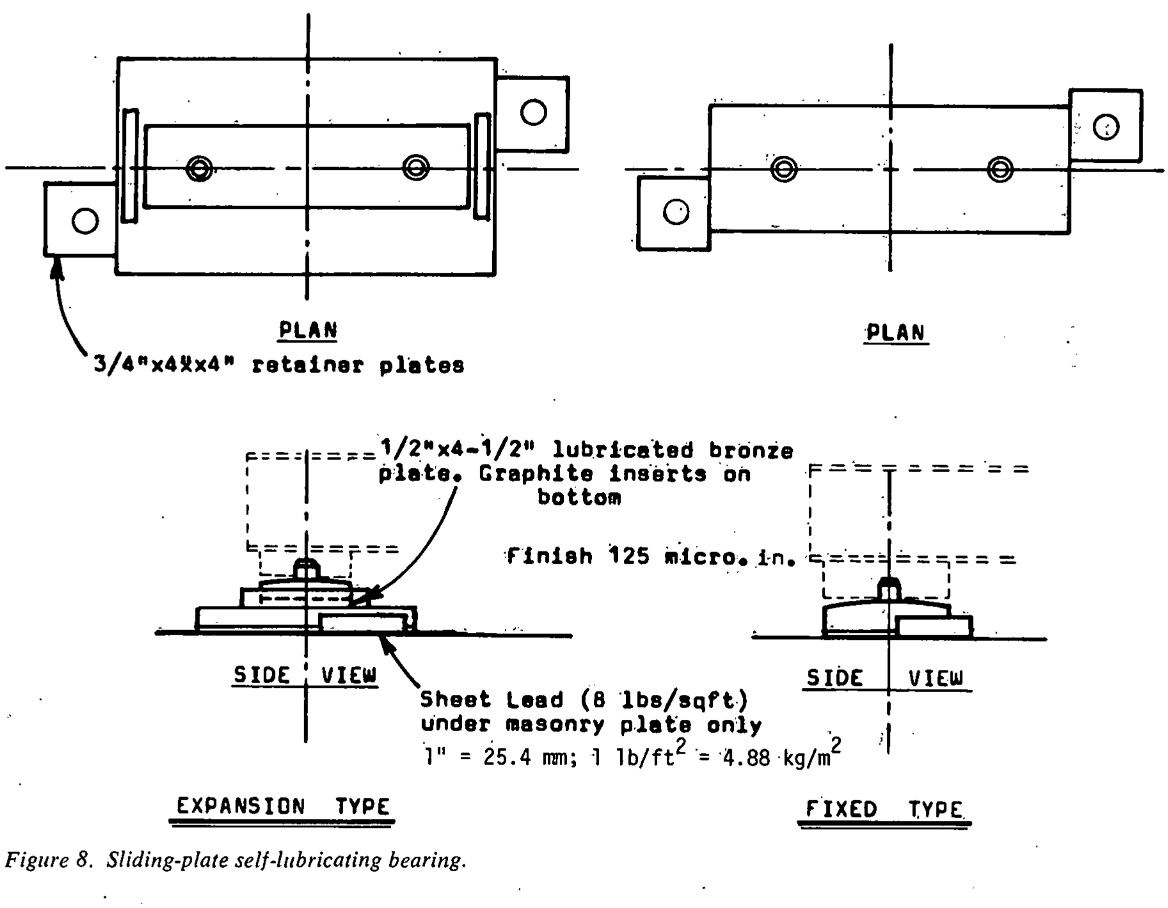


Figure 8. Sliding-plate self-lubricating bearing.

ments and consisting of graphite and metallic substances with a lubricating binder; the compound shall be pressed into the recesses by hydraulic presses so as to form dense nonplastic lubricating inserts. The lubricating area shall comprise not less than 25 percent of the total area. The coefficient of friction shall not exceed 0.10. [The bearing metal shall be one of those noted below.]

Lubrite bronze is composed of 85 percent copper, 9 percent tin, 3 percent zinc, 2 percent lead, and 1 percent nickel. Its tensile strength is 40,000 psi (280 000 kPa); yield point, 23,000 psi (160 000 kPa); elongation in 2 in. (50 mm), 25 percent; reduction in area, 15 percent min.; Brinell hardness, 80.

Other usable metals include rolled copper-alloy, AASHTO M 108 (ASTM B 100), Alloy No. 510; bronze castings, AASHTO M 107 (ASTM B 22), Alloy No. 863; Monel Metal; cast iron; stainless steel; and Meehanite.

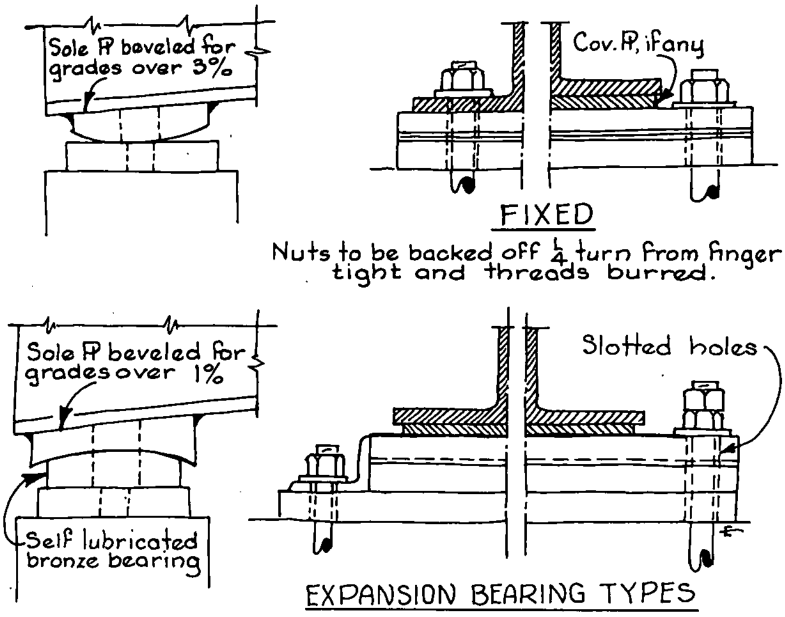


Figure 9. Self-lubricating expansion bearing for longer spans.

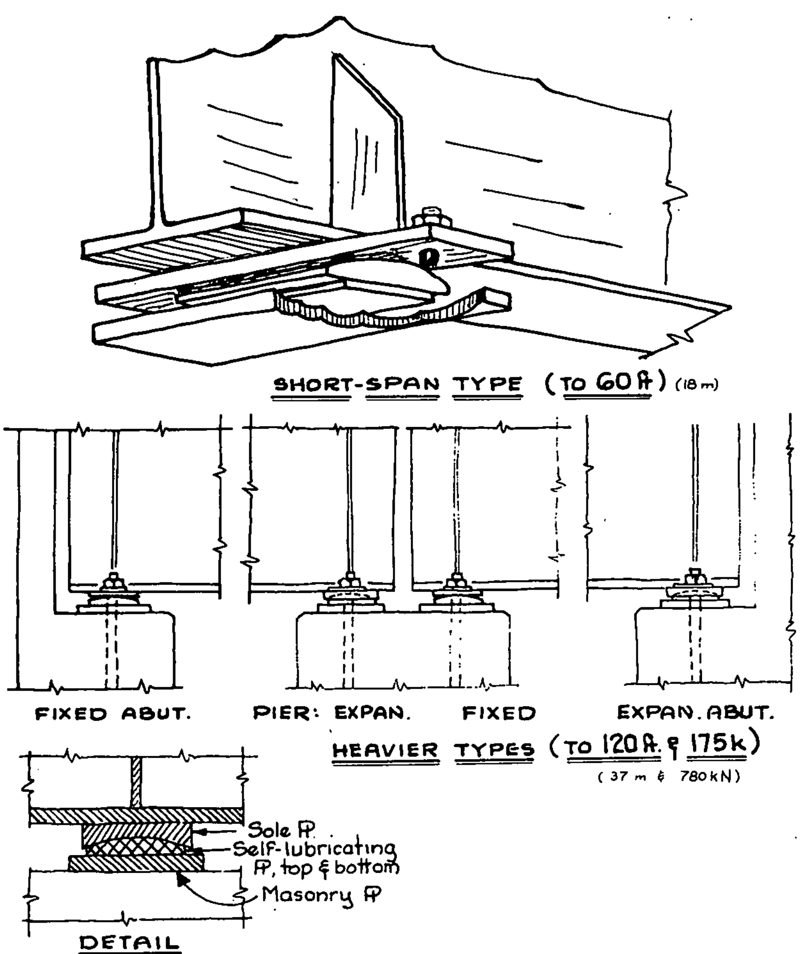


Figure 10. Curved self-lubricating bearing for steel spans.

The unit loadings can be as high as 1,200 psi (8 300 kPa) the best design values seem to be around 800 psi (5 500 kPa). Because they are a proprietary item, there is no ASTM test procedure for impregnated bronze plates.

The following is a special test procedure for the impregnated bronze expansion plates:

> The coefficient of friction shall be determined as the static coefficient while the plate is subjected to a vertical load of 1,000 psi (6 900 kPa) and after the loaded plate assembly has been subject to 1,000 cycles of ½-in. (12.5-mm) horizontal movement with one plate stationary and the other moving at a speed not to exceed 9 cycles per minute. The coefficient of friction shall be calculated by dividing the total load required to start a plate moving across the other, while subject to said vertical load, by the total vertical load. Upon completion of the test, the bronze plate shall show no signs of galling.

Somewhat similar self-lubricating characteristics are claimed for a bearing manufactured by the Chrysler Corporation called Oilite. The bronze is manufactured to be highly porous, and the open interior spaces (like a honeycomb) are charged with lubricant under pressure. Thus, the lubricant is always present between the bearing surfaces or after a surface is machined. These bearings are manufactured in a variety of shapes such as plates, bushings, and saddles to meet virtually any bearing need. Although proposed for bridges, these bearings have not been widely used for that purpose. Their principal use seems to be in the machinery field.

TFE APPLICATIONS

Polytetrafluoroethylene (TFE or PTFE) has the lowest coefficient of friction of any of the commonly available materials. It was adopted in 1960 for use in bridge bearings to provide easy movement. Many of the applications are proprietary developments of various companies and the bearings are marketed under a variety of names. Various arrangements of the materials are offered. TFE sliding on polished stainless steel has the lowest coefficient of friction. Thus, some bearings have a sheet of stainless steel under the upper steel sole plate that bears on the TFE placed on the masonry plate.

Pure TFE has a low compressive strength and a high thermal expansion; it must be combined with fillers to give it strength for use in bridge bearings. Common fillers are glass fiber and bronze. These fillers do not materially change the low coefficient of friction. Although a coefficient of less than one percent may be obtained in the laboratory, tests seem to indicate that a figure of five percent can be used for design purposes.

TFE is now being combined with Fabreeka to make a sliding bearing for shorter spans. Fabreeka is a proprietary product made of highly compressed cotton-duck layers cemented with rubber; it has long been used under base plates for bridges and for machinery resting on concrete to smooth out the small roughnesses of the concrete surface. (See "Seat Preparation," Chapter Two.)

Lubrite also makes a bearing featuring TFE called "Lubrite f." It consists of woven TFE fibers mechanically bonded to a base plate with an embossed surface. The TFE layer bears against the upper sole plate, which must be finished to about 32 μ in. (0.813 μm) rms. The assemblies may be made in almost any form, including flat plates, curved plates, and hemispheric domes for rotation in several directions. The manufacturer claims for his TFE woven fabric a coefficient of friction of less than 0.03; ultimate strength, 35,000 psi (240 000 kPa); elongation at break, 25 percent; maximum load without cold flow, 60,000 psi (410 000 kPa).

None of these proprietary bearing arrangements has been very extensively used. Accelerated tests on some thin, unbonded TFE sheets [⅛ in. (3 mm)] under pressure and movement show that the TFE flowed somewhat under the test and ended up in a dish shape indicating that it had been thinned slightly in the center area. When confined and bonded to metal plates, this effect would be minimized; there seems to be no reason why TFE should not perform over a long period of time if it is kept clean. Dust and dirt lodging between the surfaces spoils the action, however.

ROOFING FELT OR TAR PAPER WITH OIL AND GRAPHITE

Roofing felt or tar paper with oil and graphite are simple do-it-yourself bearings that are still used and work well for simple applications. They are suitable for short spans, generally less than 40 ft (12 m), where movements are small and nothing much can go wrong. They are commonly used under concrete slabs and girders on concrete abutments. The supporting concrete surfaces are smoothed, then the heavy roofing felt (or tar paper) that has been saturated with used motor oil (one state recommends 60-grade) is liberally dusted with graphite powder and laid on the bearing surface. One to three layers of 30-lb (1.46-kg/m^2) roofing felt, or any convenient number of layers of tar paper can be used. The superstructure concrete is then placed on the upper face of the "bearing." Obviously the details are not critical and even short steel spans have been placed directly on such bearings. Because the spans are relatively short, the movements small, and the paper-oil-graphite mixture able to accommodate the very slight rotation, the arrangement works quite well.

CHAPTER FOUR

ROLLING DEVICES

The problem with any rolling device is that, because the movement is small, there is a tendency for flat spots on the rollers and small dishes in the plates to develop after long use. This eventually leads to the bearing freezing. The use of high-strength steel for these elements is helpful in minimizing this distortion. A hard chrome plating has been used to minimize corrosion and preserve a hard rolling surface. However, if the plating is too thick [more than approximately 0.0025 in. (0.06 mm)], it cracks and fails. If the plating is too thin, it rusts through.

BEARING TYPES

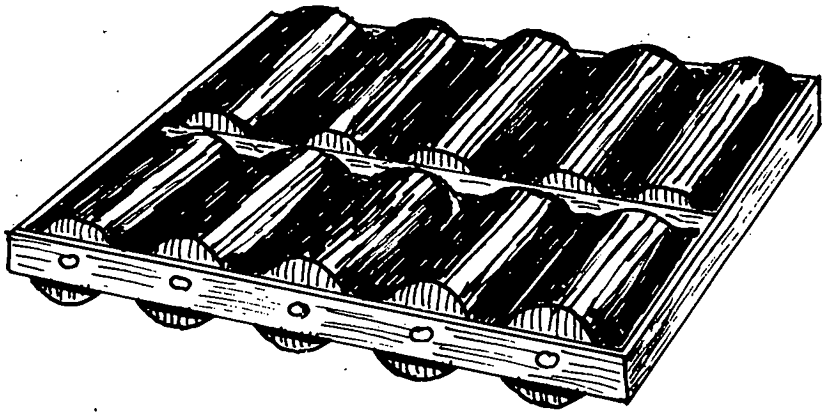
Roller Nests

In theory, roller nests appear to be the ideal solution to the expansion problem. They take up little room and provide a very low expansion coefficient between two horizontal plates. If they can be kept clean, they work well. But, as a practical matter, they can not be kept clean on a bridge. They are made up of many small rollers, which results in many small spaces where dirt can penetrate and be difficult to remove. A small amount of dirt can jam small rollers, which soon rust and eventually turn into a bed of flaked rust (Fig. 11).

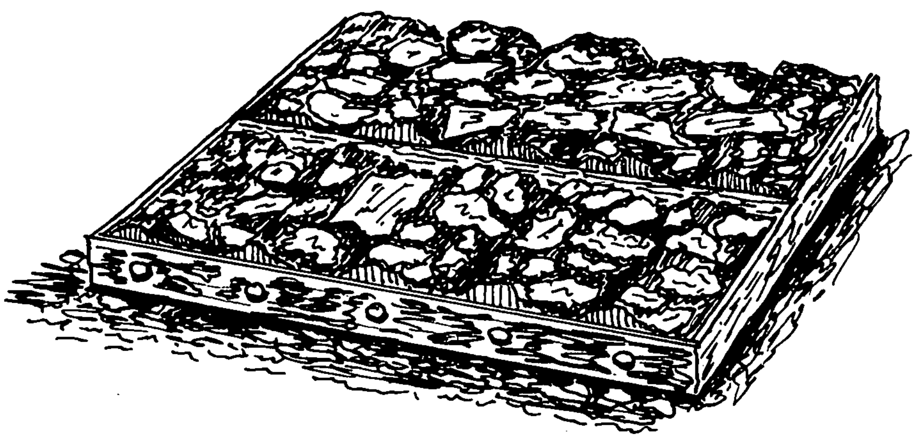
If the roller nest can be virtually sealed so that no dirt can enter, it can work satisfactorily. This is nearly impossible, however, on a bridge. Efforts have been made to build a closed housing around the roller nest and then provide grease fittings so that the entire area could be filled with grease and occasionally refilled to keep out dirt and water. This works as long as a rigorous maintenance schedule is continued; however, it rarely is. The grease melts in the heat and runs out, dirt and water penetrate, and the roller nest inevitably fails. To keep rollers parallel and separated, spacer bars are provided on each end. Small rollers require only one bar on each end, larger rollers or rockers may require two bars on each end (Fig. 12).

A variety of repair schemes has been devised to replace the roller nests with elastomeric pads, bronze sliding plates, and other devices (Fig. 13).

Roller nests are still mentioned in the AASHTO specifications (Article 1.7.52). It is noted that rollers are to be connected by substantial bars so they remain parallel and do not skew around or creep. Gear racks, guides, or other means must be provided to keep them in line and in place. Almost wishfully, the specifications then require that the rollers "shall be protected from dirt and water as far as practicable, and the design shall be such that water will not be retained and the roller nests may be inspected and cleaned easily." What the specifications do not state is that if the last provision can not be complied with completely, roller nests should not be used.



HOW THEY START OUT



HOW THEY USUALLY END UP

Figure 11. Roller nests.

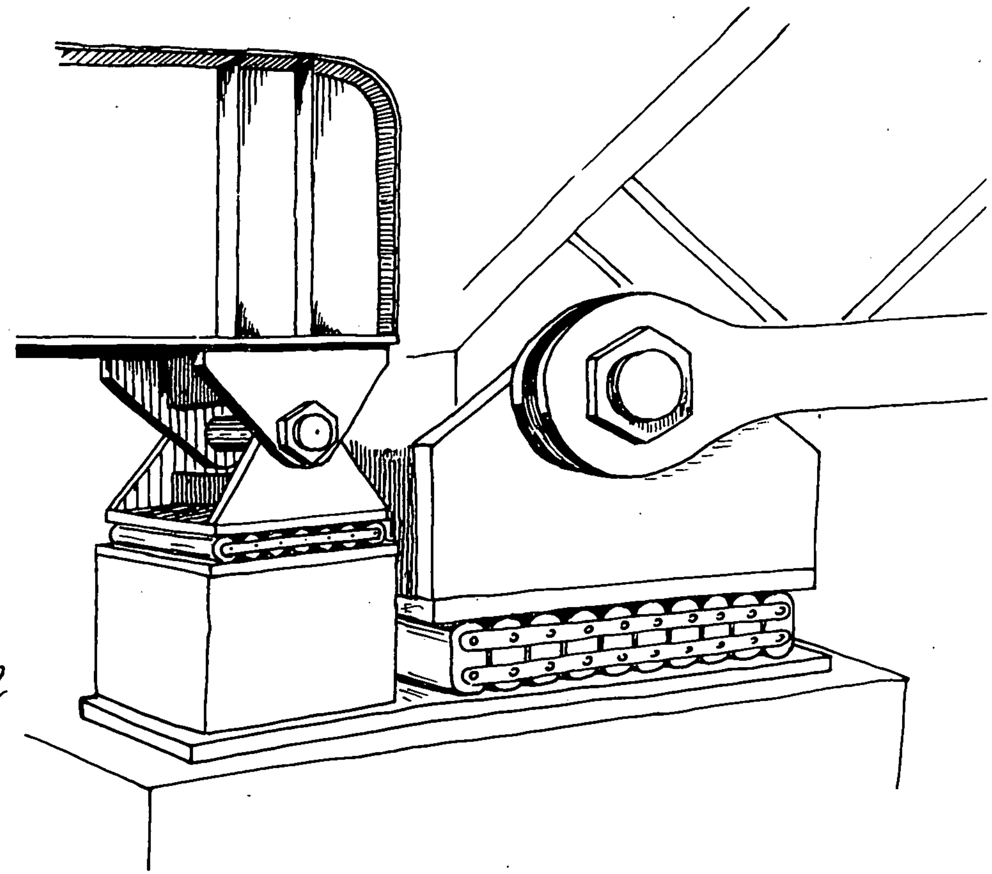


Figure 12. Roller and rocker nests. A potential source of trouble. These nests were replaced at considerable expense with lubricated bronze bearings.

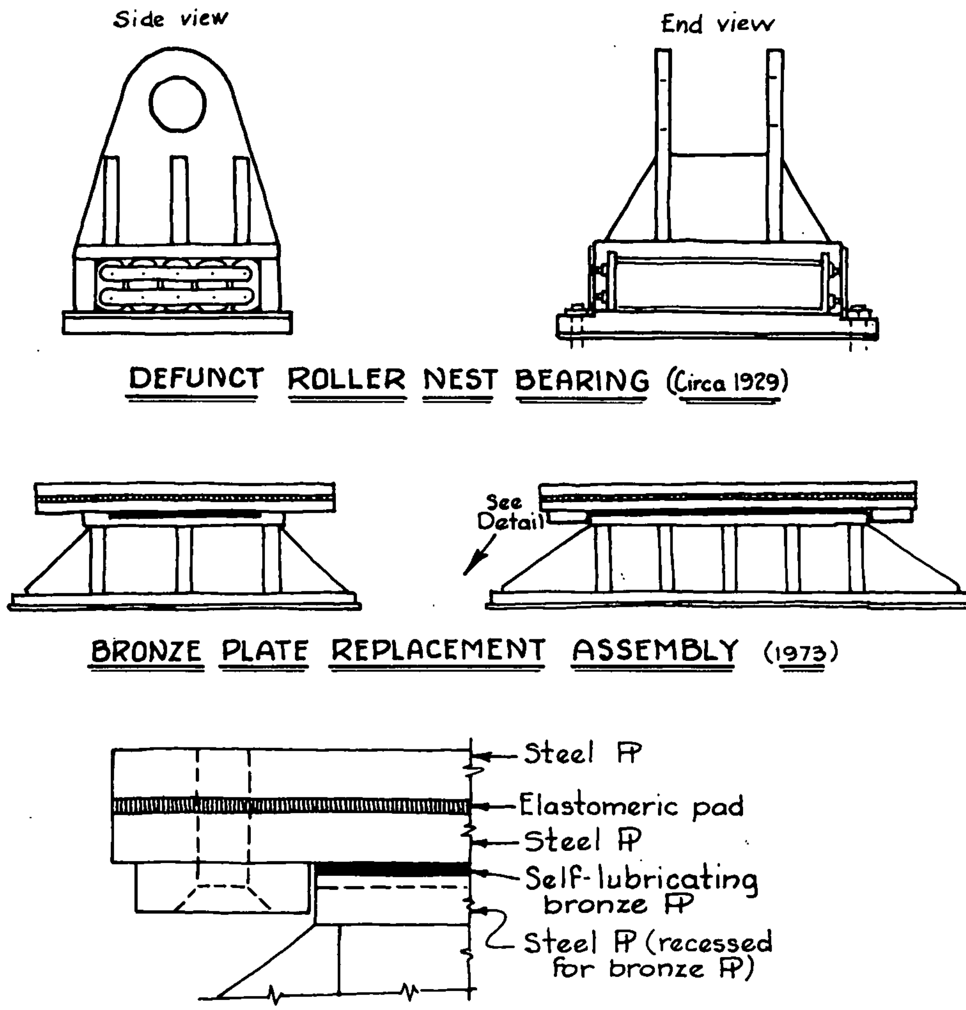


Figure 13. Repair of a roller-nest bearing, 140-ft (43-m) truss.

A number of very large rollers [14 in. (360 mm)] were grouped as a roller nest for a long span with large movement (Fig. 14). These were enclosed as nearly as possible; their large size should resist penetration and jamming by dirt.

Single Rollers

The failure of the roller nest idea does not condemn the use of rollers. Next to elastomeric pads, the roller and adaptations of it are the most widely used bridge expansion device. The faults of the roller nest are mainly its small size, intricate detail, and inaccessibility for cleaning and maintenance. Larger, simpler, and more open single rollers were designed to alleviate this problem. It was reasoned that small bits of dirt that would jam a 1½- or 2-in. (40- or 50-mm) roller would be crushed and rolled over by a single roller that was 4 in. (100 mm) or larger (Fig. 15). With a large single roller, the bearing detail is open and is frequently cleaned through wind action (Fig. 16).

Rollers 6 in. (150 mm) and larger perform well if they are well designed and built so that they are protected from weather, roadway salt, dirt, and abuse. They also require less repair if given even occasional cleaning and attention.

Because only a small portion of the circumference of a roller is actually used and because this is the area in which water and dirt collect, this bearing area can become badly corroded. There have been many cases in which badly corroded rollers were turned 90 degrees to bring two new faces into contact. The corroded area still remains on the plates, but it can be regarded as a 50 percent improvement. This is, of course, a temporary repair made to keep things working until money can be found for a more complete improvement.

A roller left to its own devices (i.e., rolling back and forth between two horizontal plates) gradually works its way out from under the bridge. It is necessary, therefore, to provide pintle pins to keep it in place. These pins are usually set tightly into the lower element, two on top and two on the bottom, along the line of contact of the roller and plates. The pins project into holes in the plates with a loose fit, permitting the roller to move back and forth but preventing it from straying from proper position (Fig. 17).

Various arrangements of rollers have been made using them more as wheels, with the bearing axle considerably smaller than the bearing roller (Fig. 18). Although the

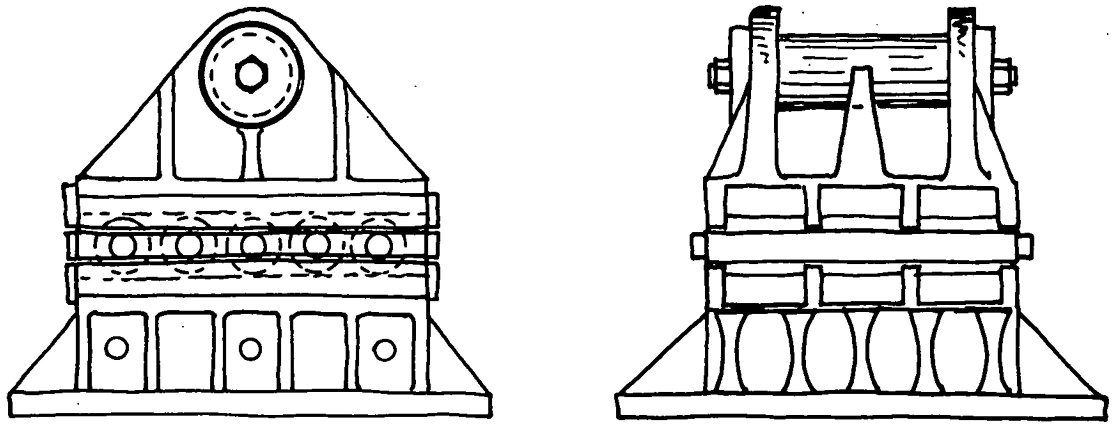


Figure 14. A roller nest assembly for a large bridge (1973). The bearing assembly is more than 8 ft (2.44 m) high and the five rollers are each 14 in. (360 mm) in diameter. The large pin is 20 in. (500 mm) in diameter. The rollers are hard chromium plated all over, as is the 4-in. (100-mm) shaft on which they run. Bronze bushings and lubrication are provided for all bearings. Load is more than 10,000 kips (45 000 kN).

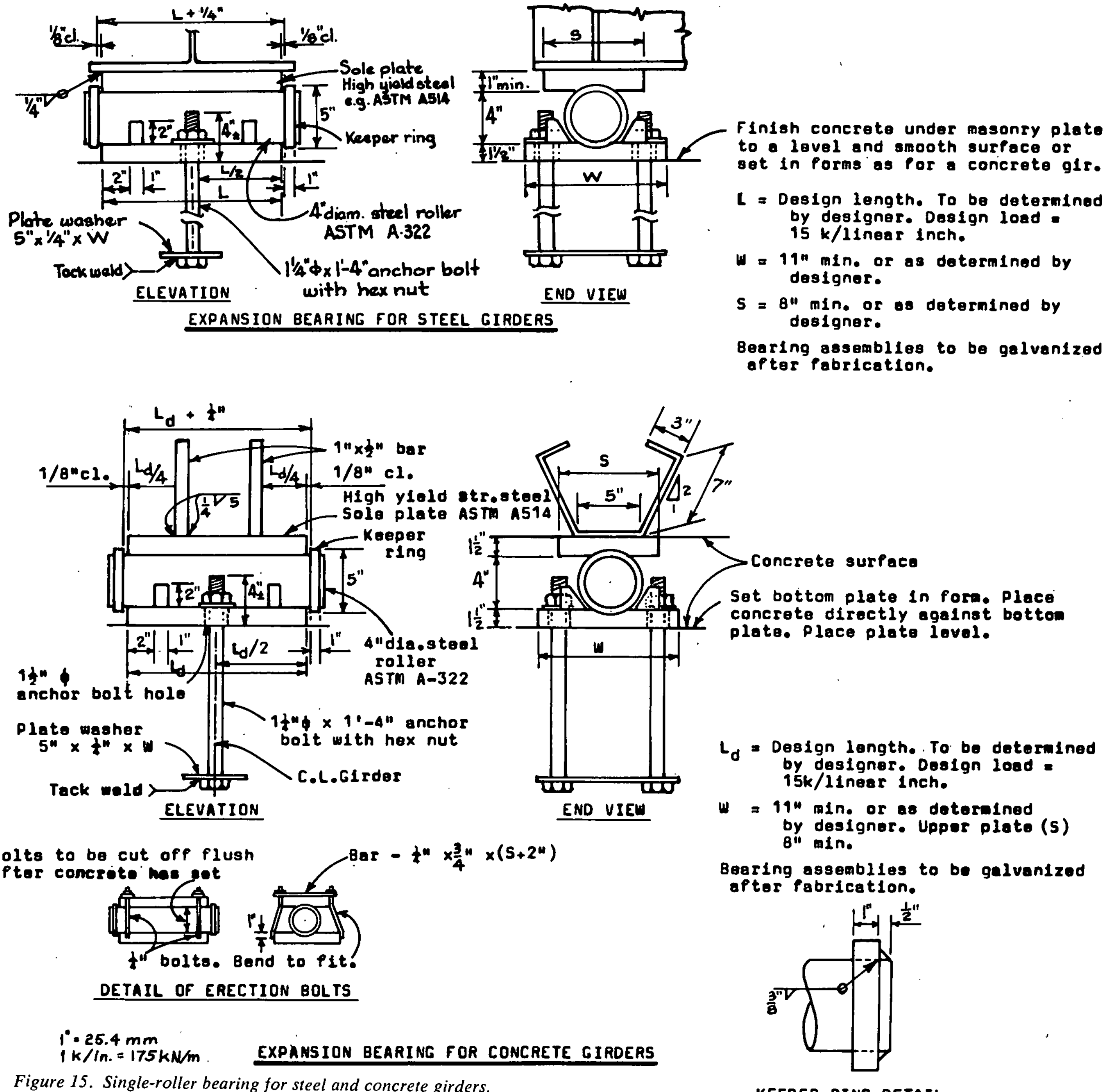


Figure 15. Single-roller bearing for steel and concrete girders.

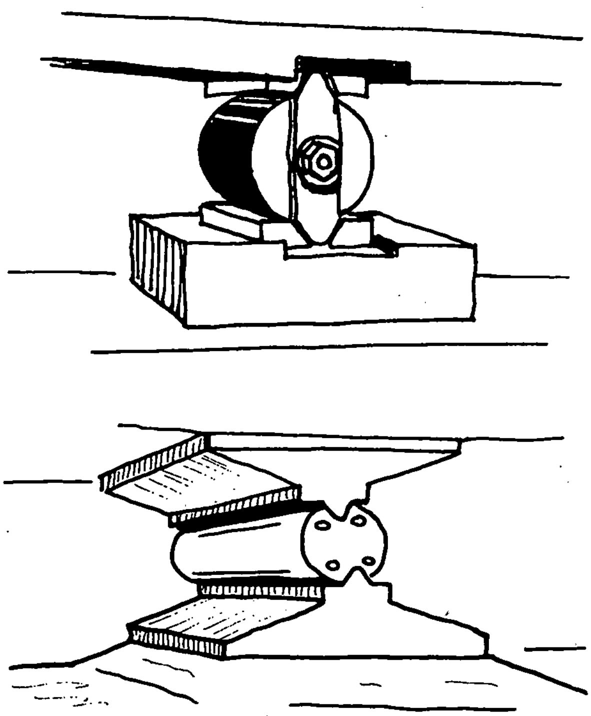


Figure 16. Single-roller bearings (European).

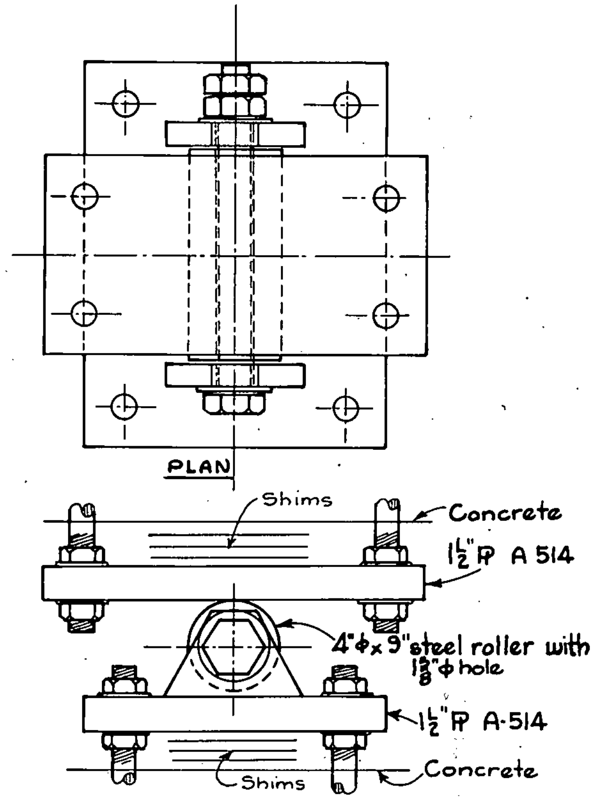


Figure 18. Roller bearing for long concrete span.

wheels were sometimes of huge proportions, they were not lubricated and the bearing froze. The smaller shaft is the vulnerable point. Figure 19 shows such a bearing in which the wheels are about 4 ft (1.2 m) in diameter and the shafts have a diameter of approximately 1 ft (0.3 m). The whole assembly locked up. Figure 20 shows a modern use with a 10-in. (250-mm) roller and a 5-in. (125-mm) shaft.

Segmental Rockers

As larger rollers were used in designs, it became obvious that these rollers work better. They afford less room for dirt to penetrate the critical area and, when it does penetrate, the larger roller can crush and roll over it easier than small rollers.

However, 10-, 12-, or 18-in. (250-, 300-, or 460-mm) rollers are very heavy and hard to handle. In service, only a small portion of the circumference is used depending on the amount of movement. Thus, if the unused portion of the roller is cut away, considerable weight and space are saved; at the same time, the bearing still functions as

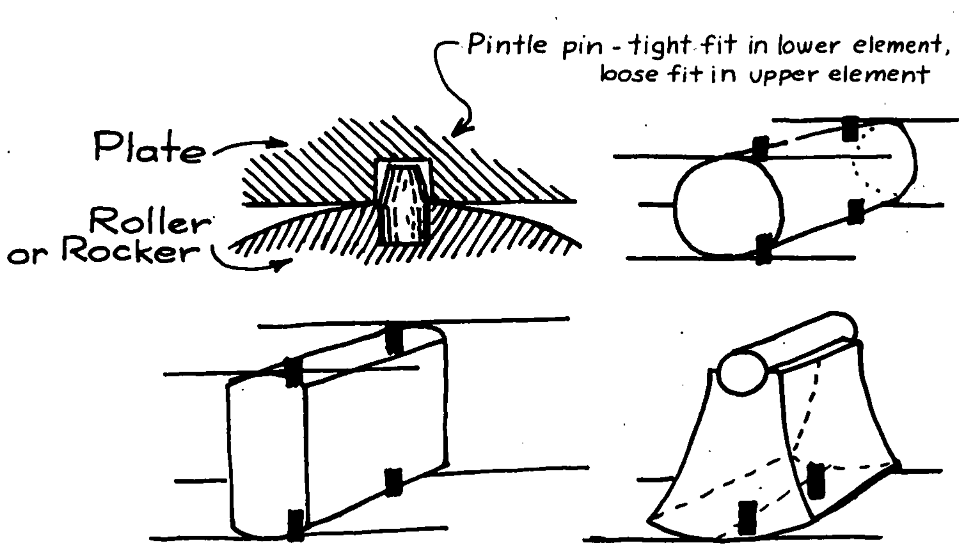


Figure 17. Pintle pins.

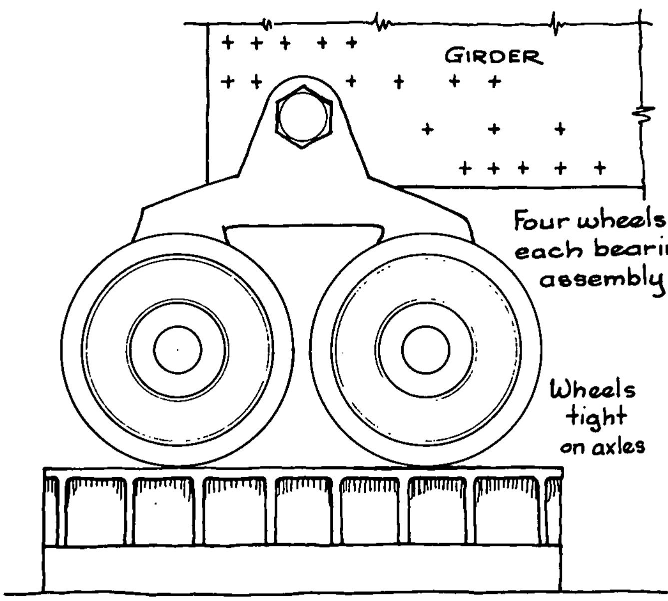


Figure 19. Bearing for a two-span truss bridge (1929). The axles froze in their bearings, locking the wheels which then just slid back and forth on the cast-iron bearing block.

though it were a whole cylinder. This solution to the size problem of large rollers is called a segmental rocker (Figs. 21 and 22). Care should be taken in design to be sure that the rockers will be able to accommodate expected movement without tipping over.

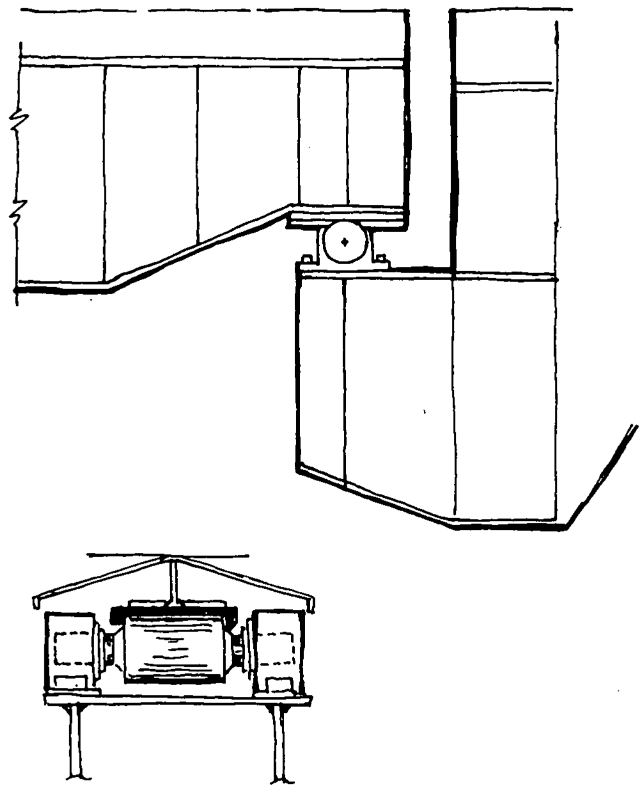
When segmental rockers came into use, they did not have to be trimmed from a cylinder; they could be made so that the radii of the two faces would be greater than half the depth of the rocker. This should not be carried to an extreme, however, because geometry causes the bridge to rise slightly at each end of the movement range. Normally this is not objectionable; the fact that the resisting force increases on either side of the median line may help to keep the rocker in position.

Pinned Rockers

These bearings (Figs. 23, 24, 25, 26, and 27) are a modification of the segmental rocker and are probably the most popular rocker design today. Their advantage is that the pin connection tends to keep the bearing aligned correctly. However, the bad features may outweigh the good; pins are notoriously susceptible to corrosion and freezing. They are still used, however, for relatively long spans and heavy loads.

Pins are often retained by nuts on each end. These should be secured by cotter pins or tack welds.

The tendency for these bearings to freeze seems to defy reason. Considering the irresistible forces, one would think that a bearing consisting of a 2- or 3-in. (50- or 75-mm) pin above and a large rocker below would be likely to move. Such is not always the case. They frequently freeze and rock the pier back and forth. This was dramatically shown in a recent test on a bridge in Missouri. A fairly modern steel-girder bridge was tested to destruction by applying a large oscillating load in mid-span. The gyrations of the bridge were large and spectacular. One expansion bearing consisting of a pin above and a rocker below was frozen about 20 degrees out of plumb. Movies of the action showed that the bearing did not move but that the pier itself moved longitudinally several inches with each oscillation. BEARINGS WILL FREEZE!



ROLLER DETAIL
Note the protective roof

Figure 20. Roller bearing for a suspended span in a truss has 10-in. (250-mm) roller with 5-in. (125-mm) shafts; a very expensive bearing. The expansion of 1,200 ft (366 m) of truss is accommodated at this point.

Rack and Pinions

For the largest spans, pintle pins are not adequate to keep bearings aligned. The forces can become so large that the pins can be sheared off and the bearing turned. To keep the rollers aligned, rack and pinion systems have been developed. On each end of the bearing, a pinion is rigidly attached to the shaft of the bearing (Fig. 28). This pinion runs in two racks (one above and one below) attached to the superstructure and the supporting structure. The pinions carry no weight. Their function is to keep the bearing rollers aligned. They must be carefully maintained, but are usually used only on large bridges where a regular maintenance program is provided.

Steel Balls

Balls have rarely been used to carry loads and accommodate longitudinal movement because of the difficulty of keeping

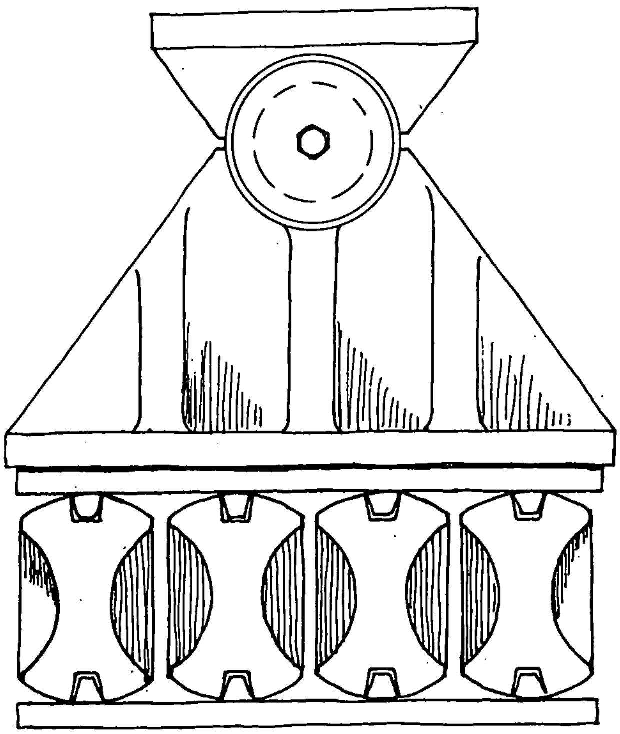


Figure 21. Segmental rocker nest for a large bridge (1964). The whole bearing assembly is about 3.5 ft (1 m) high. The rockers are approximately 1 ft (0.3 m) high and 7 in. (180 mm) wide. The upper pin is 6 in. (150 mm) in diameter.

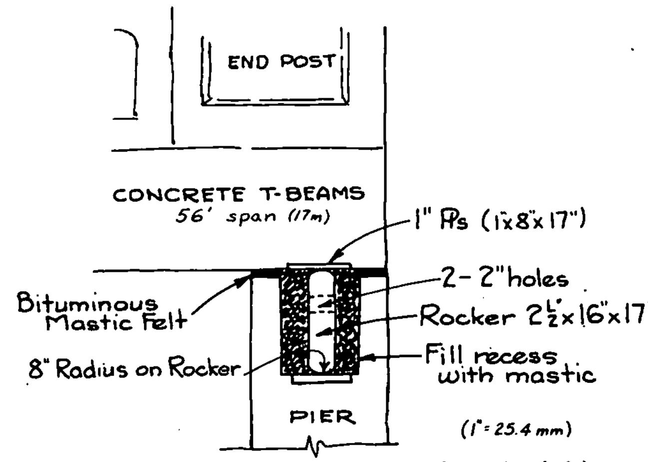


Figure 22. Rocker bearing for concrete T-beam (archaic).

them in place. They have been used, however, for the base or top of a slender column to accommodate small rotation or deflection movements in any direction. They are very difficult to maintain in good working condition because of corrosion danger. Grease grooves and frequent greasing, or complete enclosure of the space with grease is helpful; however, steel balls are still likely to freeze without constant attention.

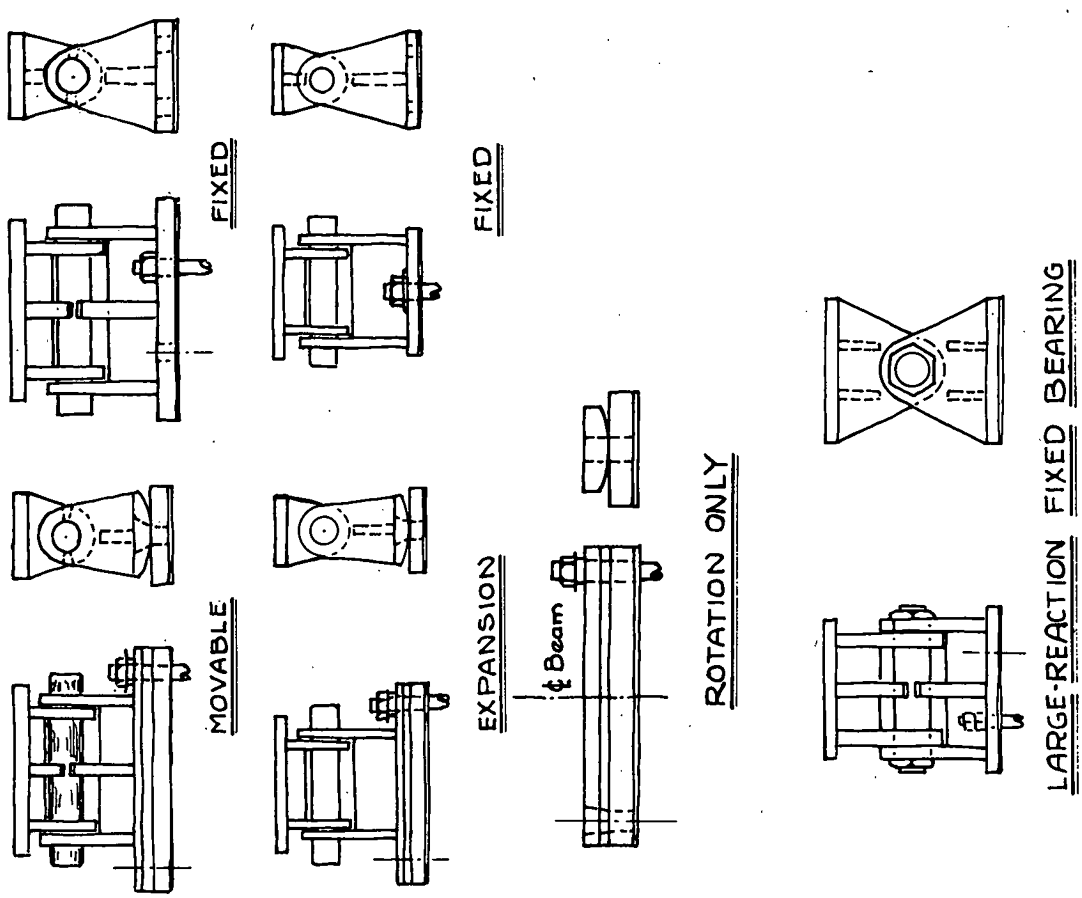


Figure 23. Steel rockers and pinned bearings.

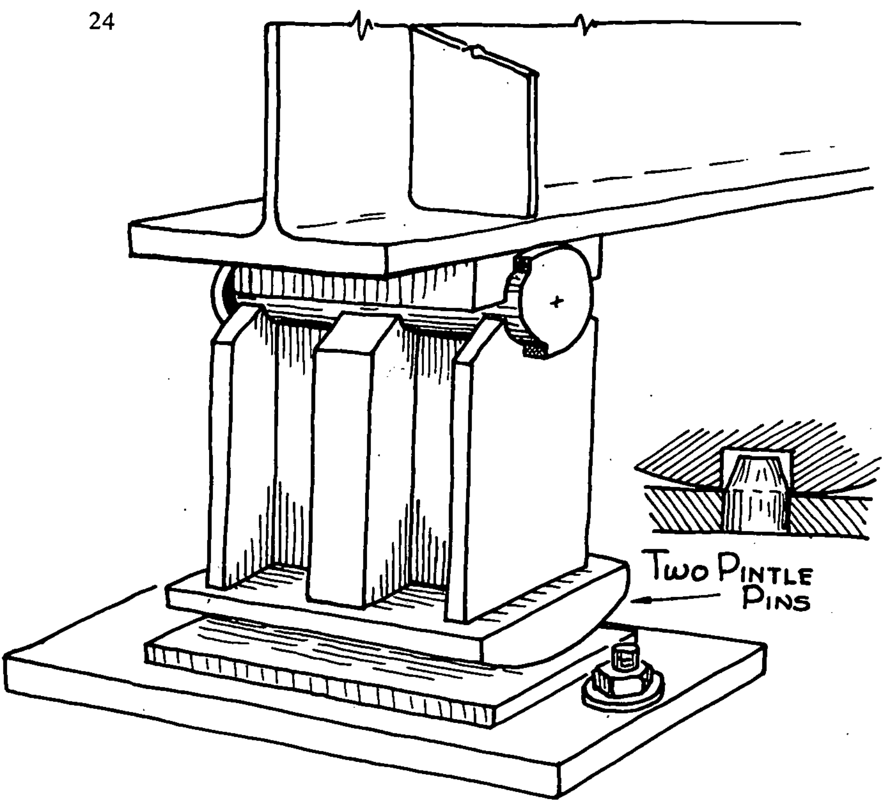


Figure 24. Heavy-duty expansion shoe (1975).

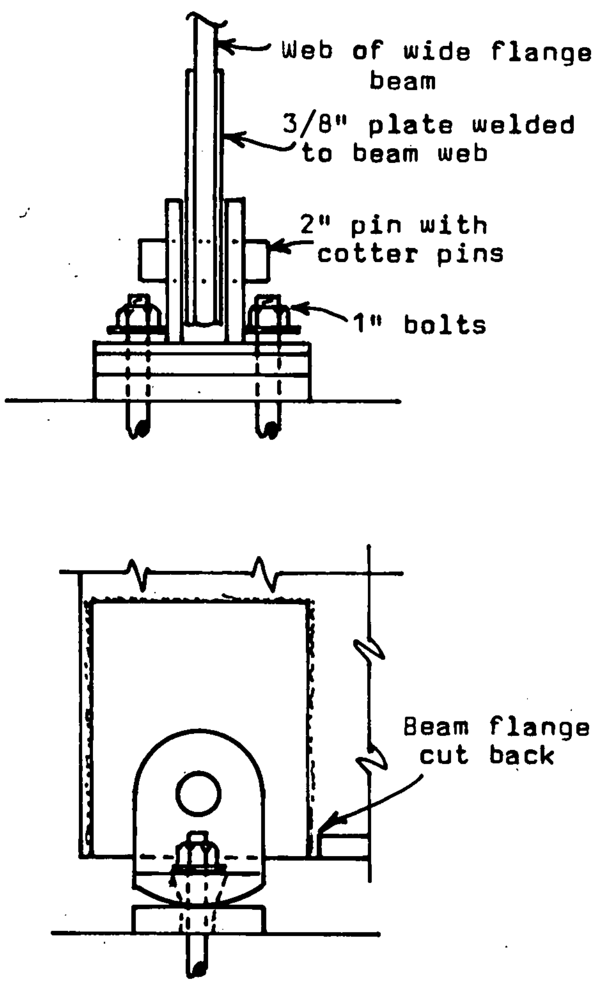


Figure 26. Rocker bearing for a 52-ft (16-m) rolled beam (archaic). The pin froze in the web and locked the joint.

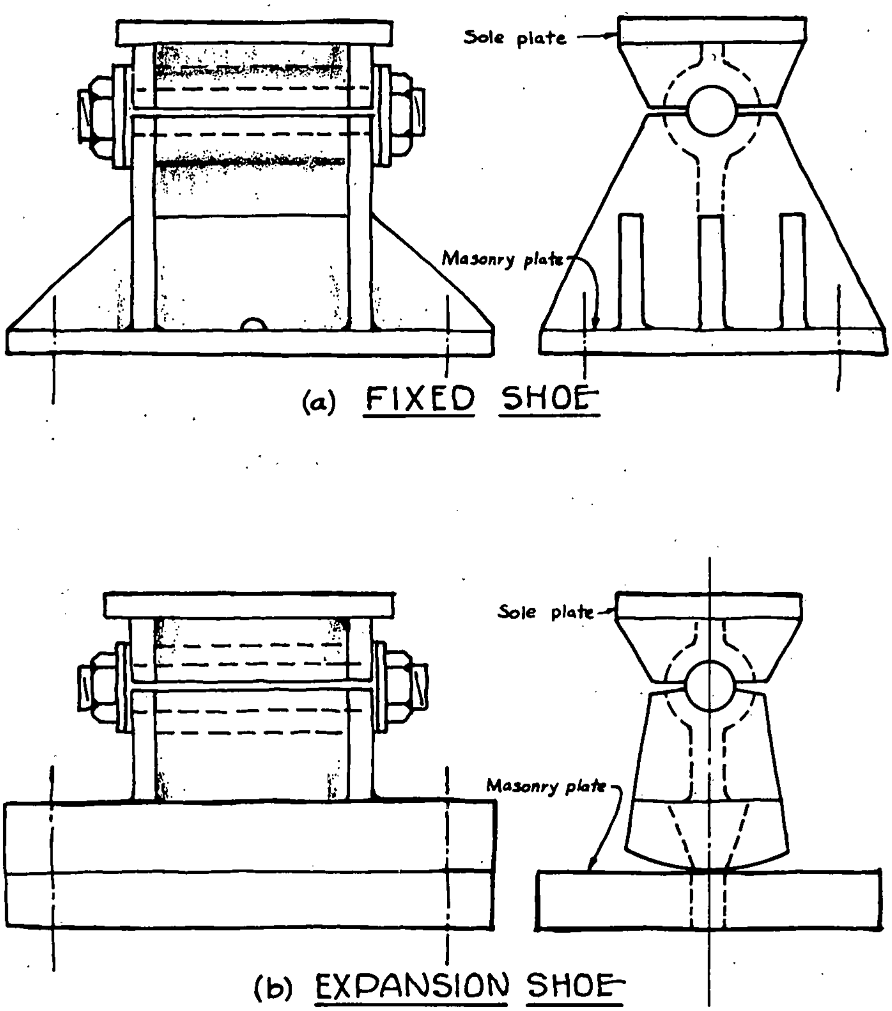


Figure 25. Bearing shoes for continuous steel bridges (1944).

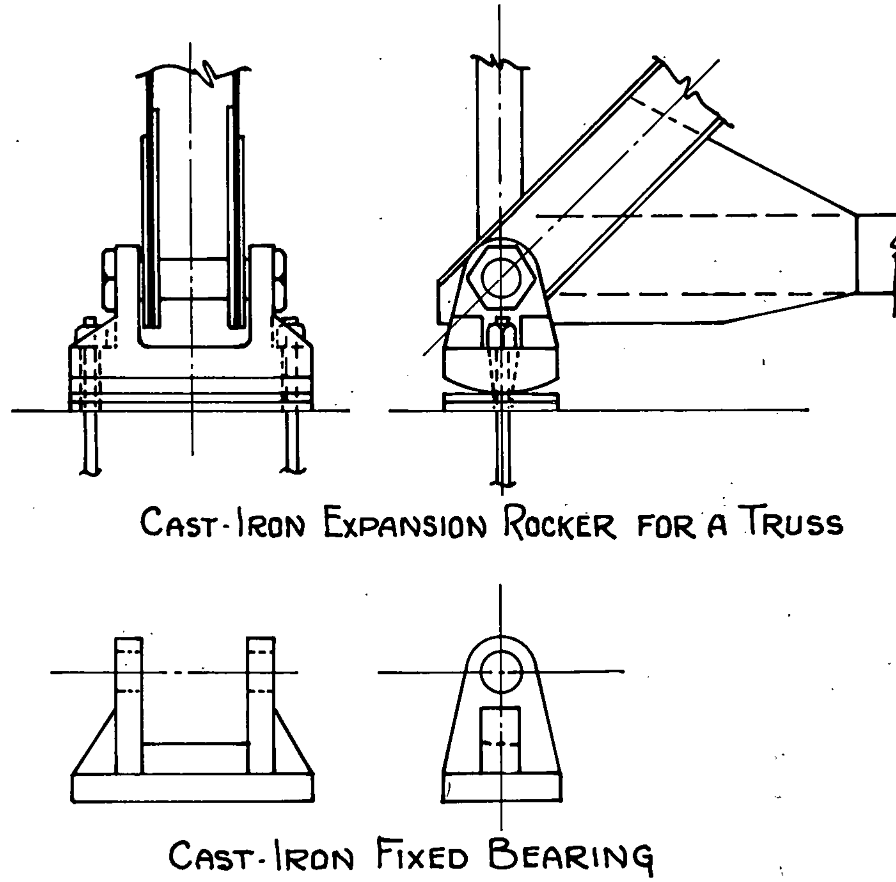


Figure 27. Cast-iron bearings (archaic).

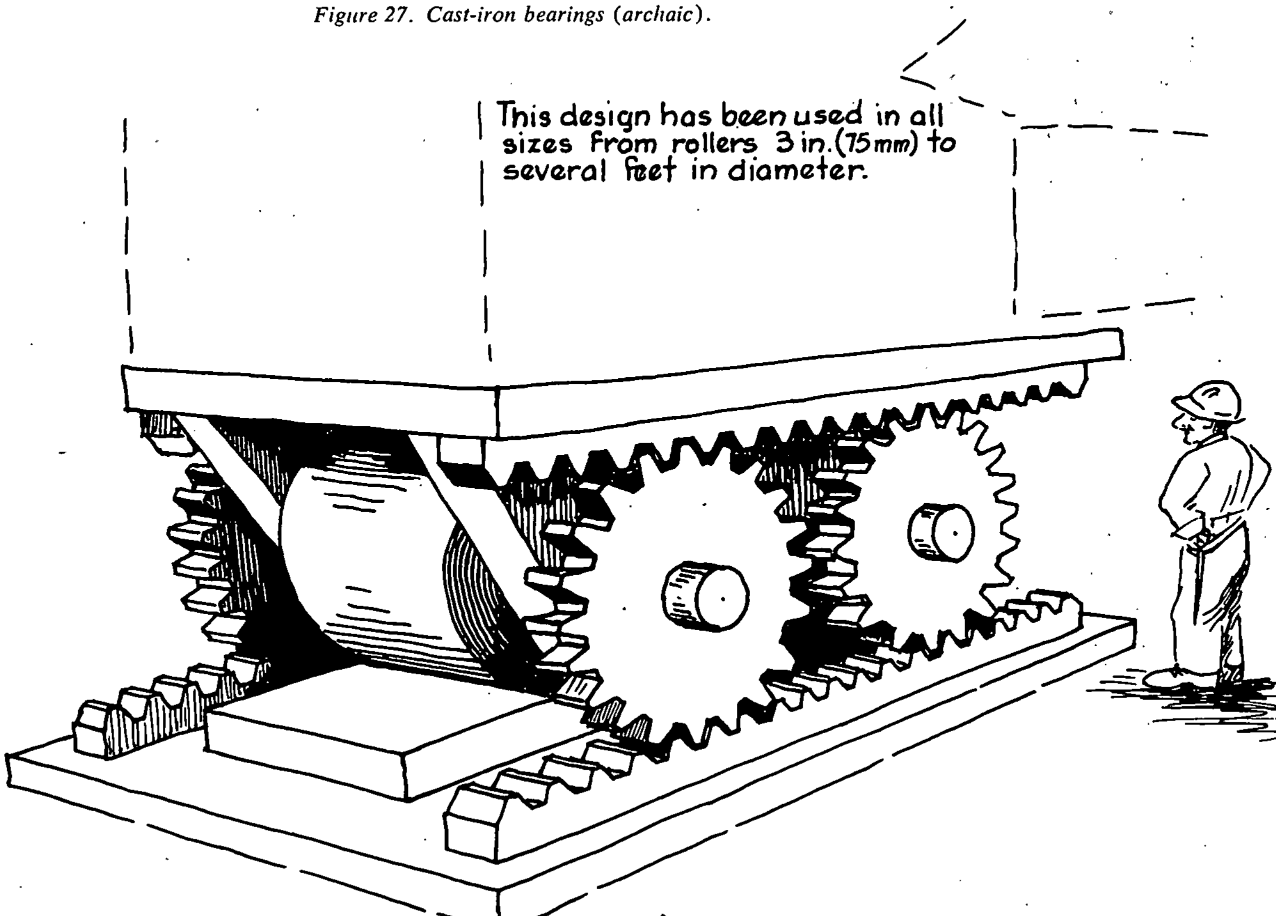


Figure 28. Rack and pinion (geared) bearing. (For very long spans.)

DESIGN CONSIDERATIONS

The design of expansion rollers and rockers is a good exercise in practical engineering. A theoretician has trouble with the design of a roller bearing. Acknowledging that the allowable load is the product of contact area times allowable unit stress, the theoretician is immediately confronted with the fact that the contact area is a line of virtually no width. The bearing area of a ball bearing on a flat plate is a point of no linear dimension at all. Thus, total load divided by contact area (zero) gives a stress of infinity. However, because the machinery of the world runs successfully on ball and roller bearings, it is known that the unit stresses are not necessarily infinite as the theory indicates but are, in fact, reasonable. These bearings operate well under a reasonable load. The same is true of bridge rockers and rollers.

In the U.S., designers use high-strength steels to avoid distortion and to maintain smooth rolling surfaces; in contrast, Europeans prefer the hardening or hard-facing of rollers. This method produces hardnesses of Brinell 500 to 600 with a rolling friction of only 1 or 2 percent. The specified design load is 12.5 kips/in. of diameter per in. of length (86 N/mm of diameter per mm of length). A design rolling friction of 3 percent is recommended.

The AASHTO recommendation for the design of rollers and rockers (Article 1.7.4) is as follows:

Bearing per linear inch on expansion rockers and rollers shall not exceed the values obtained from the following formulas:

Diameters up to 25 in. (640 mm):

$$p = \frac{F_y - 13{,}000}{20{,}000} 600\, d \left(p = \frac{F_y - 90{,}000}{138{,}000} 4.14\, d\right)$$

Diameters 25 to 125 in. (640 to 3 200 mm):

$$p = \frac{F_y - 13{,}000}{20{,}000} 3000\sqrt{d} \left(p = \frac{F_y - 90{,}000}{138{,}000} 105\sqrt{d}\right)$$

where:

p = allowable bearing in pounds per linear inch (N/mm);
d = diameter of rocker or roller in inches (mm);
F_y = minimum yield point in tension of steel in the roller or bearing plate, whichever is smaller (psi or kPa).

Steel may conform to one of the following designations:

- Cold-Finished Carbon Steel Bars and Shafting, AASHTO M 169 (ASTM A 108)
- Steel Forgings, Carbon and Alloy, for General Use, AASHTO M 102 (ASTM A 668)

Allowable stresses shall not exceed those in Table 5.

In addition, steel may conform to one of the designations used for shapes and plates: AASHTO M 183 (ASTM A 36), AASHTO M 161 (ASTM A 242), AASHTO M 187 (ASTM A 440), AASHTO M 188 (ASTM A 441), AASHTO M 223 (ASTM A 572), AASHTO M 222 (ASTM A 588), AASHTO M 244 (ASTM A 514), and ASTM A 517.

Bearing Plates

Sole plates and masonry plates (Fig. 25) should be designed to be not less than ¾ in. (19 mm) thick. In most cases, thicker is better. Extra thickness in bearing plates is not wasted. They are seldom an expensive item, and specifying an adequate thickness is good insurance. A plate that

TABLE 5

ALLOWABLE STRESSES (psi) FOR EXPANSION ROLLERS

AASHTO Designation with size limitations		M 169 (4" in dia. or less)	M 102 (to 20" in dia.)	M 102 (to 10" in dia.)	M 102 (to 20" in dia.)
ASTM Designation with grade and class		A 108 Grade 1016 to 1030 inc.	A 668 Class D	A 668 Class F	**A 668 Class G
Minimum Yield Point	F_y	36,000*	37,500	50,000	50,000
Stress in Extreme Fiber	$0.8\ F_y$	29,000*	30,000	40,000	40,000
Shear	$0.4\ F_y$	14,000*	15,000	20,000	20,000
Bearing on pins subject to rotation (rockers and hinges)	$0.4\ F_y$	14,000*	15,000	20,000	20,000

*For design purposes; not a part of A 108 specifications. Supplementary material requirements should provide guarantee that material will meet these values.

**May substitute rolled material of the same properties.

10,000 psi = 69 000 kPa
1 in. = 25.4 mm

is too thin develops curvature so that the bearing lies in a sag and the loads are not distributed equally over the pier surface but are concentrated in a narrow area, causing a wide variety of problems. Experience has shown, however, that the higher strength steels, such as ASTM A 514, result in a better service life with lower maintenance costs and have less tendency to curl.

Some designers like to make the sole (upper) plate much larger than the masonry (lower) plate to achieve an umbrella effect that shields the bearing from water, dirt, and falling debris. Keeping any bearing clean is a major problem.

Pedestals and Shoes

The earliest pedestals and shoes were cast iron or steel; however, with the development of welding, it has become more popular (and usually cheaper) to fabricate them from welded plates. This practice has led to at least two difficulties. The plates used were often too light and the pedestals would deflect or even collapse under load. In addition, when the individual weldments were very heavy, tremendous internal stresses were locked up in the unit caused by the differential cooling of the various parts. Warping was common until procedures were worked out to minimize distortion and until stress-relieving became a common requirement.

Pedestals or shoes can be either cast steel or welded structural steel. The difference in width between the top and bottom bearing surfaces must not exceed twice the distance between them. In built-up units, the web plates and the angles connecting them to the base plate should not be less than ⅝ in. (16 mm) thick. If the pedestal is large enough, it should have its webs rigidly connected transversely. The minimum thickness of metal in cast-steel units is 1 in. (25 mm). Pedestals and shoes must, of course, be designed so that the load is spread uniformly over the base areas. Webs and pin holes must be arranged to minimize eccentricity. The net section through the hole must provide 140 percent of the net section required to carry the load on the bearing. Pins of course must be long enough to secure a full bearing and should be retained by nuts and washers so that they can not work out. The pedestal or shoes must be secured against lateral movement against the pins (AASHTO 1.7.56).

The AASHTO specifications include many provisions relating to the fabrication and construction of pedestals and shoes. Each of these provisions has been included because of some prevalent difficulty that has arisen. It is well, therefore, to adhere quite closely to the stated provisions.

CHAPTER FIVE

LINKAGE OR EYEBAR DEVICES

SIMPLE LINKS

For expansion connections between girders where no moment is to be transmitted across the joint, simple-link hangers are usually used (Fig. 29). These work very well with steel plate girders where the pins can be inserted through a locally strengthened section of the web. Hangers have also been used in concrete construction; however, the arrangement is cumbersome. For concrete, a simple step bearing with an elastomeric pad is preferred (Fig. 30).

Links have also been used as expansion bearings; however, there are many parts that can corrode and freeze. In addition, the short link causes the deck to rise and fall (Fig. 31).

The condition of the link pins or bearing is almost impossible to inspect after assembly. Thus, they should be a minimum of 4 or, preferably, 6 in. (100 or 150 mm) in diameter. The pins are sometimes fitted with grease grooves and fittings so that they can be greased for lubrication and so that dirt and water are kept out of the bearing areas. Access is often difficult, however, and reliance on any maintenance procedure is not advisable.

Pins are usually retained by nuts on each end. These should be tack welded to prevent removal. Nuts and even pins have been stolen by souvenir hunters. The tack weld should not be used on a high-strength steel. Such tack welds to an A 514 web initiate small shrinkage cracks radiating out into the web plate, which can result in an expensive repair job.

The steel girder web is reinforced on each side to provide sufficient bearing area for the pins. Further arrangements are often provided to stiffen the joint so that torsion stresses are also transmitted across the joint. This serves to keep the two plate girders in good alignment.

LONG COMPRESSION STRUTS

On long bridges where large temperature movements must be accommodated, long compression struts are often used as end bearings. On the San Francisco-Oakland Bay Bridge for instance, there are compression struts about 50 ft (15 m) long going down into wells in the center anchorage. One strut at each corner supports the spans coming into the anchorage. At the towers, each corner of the trusses is supported on shorter compression struts about 10 ft (3 m) long.

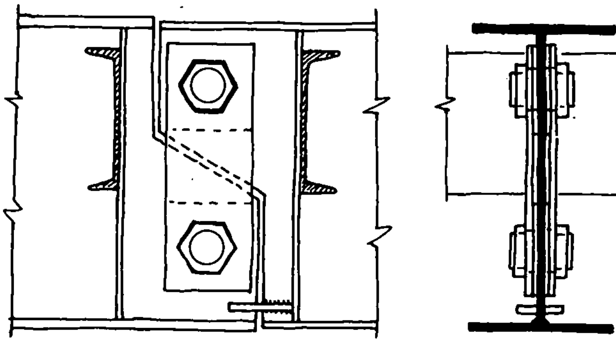


Figure 29. Link hanger for a welded plate girder.

Often in cantilever spans, the supporting strut under the end of the anchor span has to serve both as a compression and a tension member (Fig. 32). If the stress is all tension, then the support may be eyebars. The long length provides for ample movement and the long radius makes the rise and fall of the deck infinitesimal.

Many concrete bridges are now being built in which the tall, slender piers are actually moving compression struts. The difficulties and complications of movable bridge bearings have led to bridges without intermediate expansion bearings, relying on the slenderness of the piers to absorb the movement.

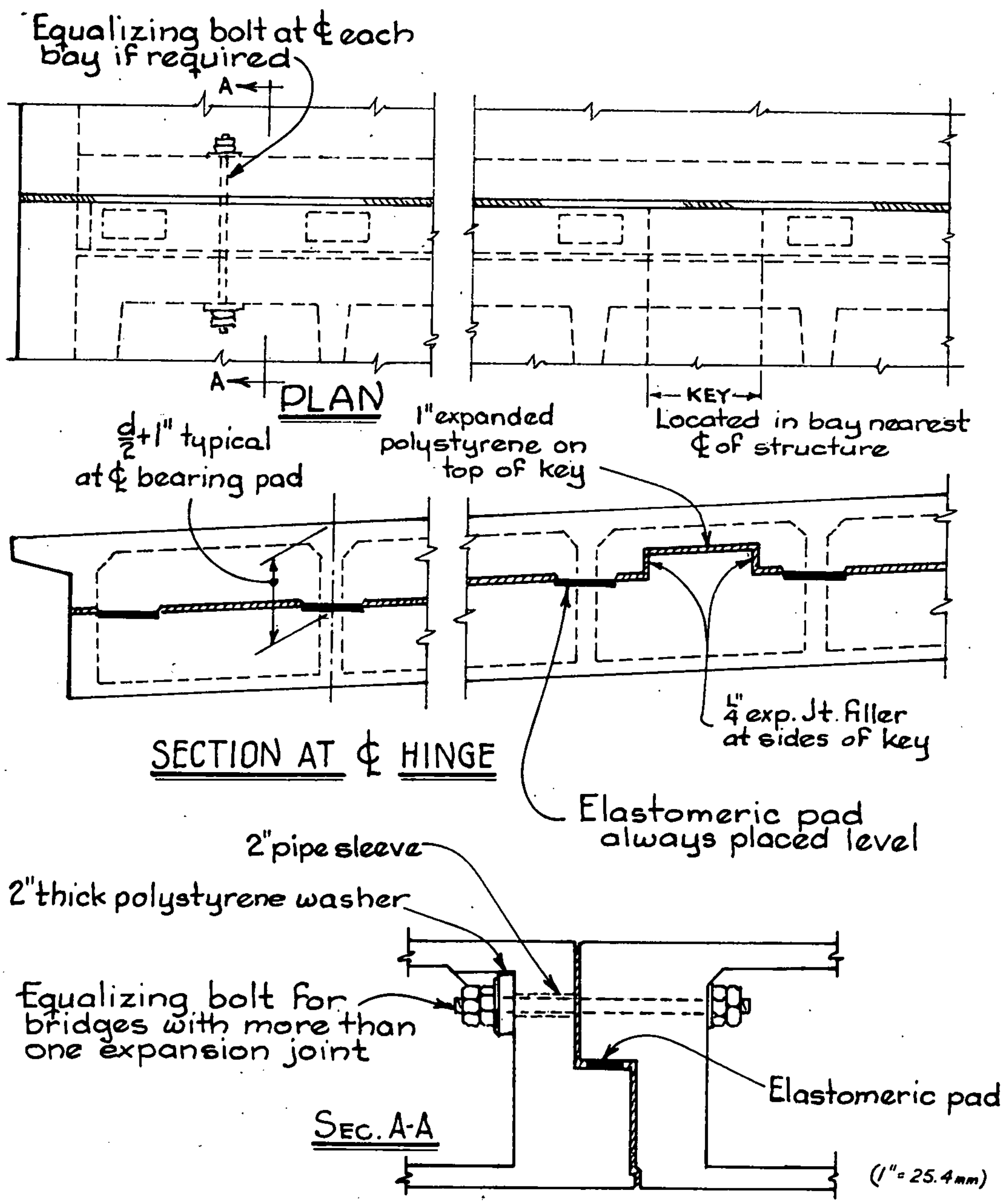


Figure 30. Elastomeric-pad expansion detail for concrete box girder.

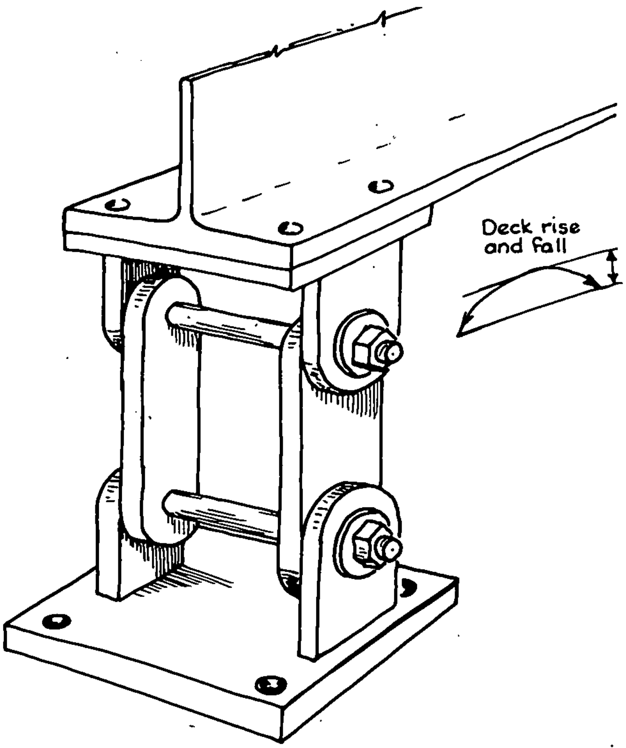


Figure 31. Link expansion bearing. A good idea that does not work. Too many moving parts to corrode and freeze. Movement causes deck to rise and fall.

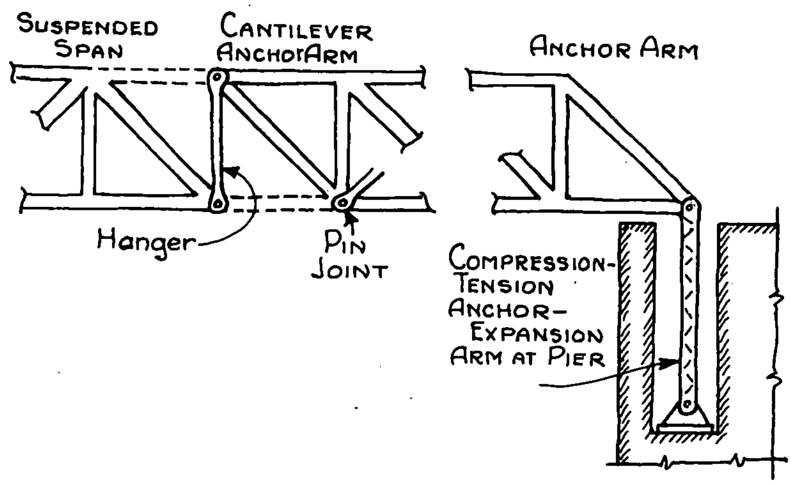


Figure 32. Compression-tension bearing strut.

PINS FOR ROTATION WITHOUT HORIZONTAL MOVEMENT

There are situations in which a pin is used to transmit vertical shear and transverse loads (such as wind loads), yet carry no moment through the joint and allow no horizontal movement. These are often used in steel girder spans with either welded or rolled girders. The web plates are reinforced and a simple toggle-type joint is created (Fig. 33). If these pins are made large [6 in. (150 mm) or more], the wear is negligible with characteristically small movements and there should be no trouble. Pins are often fitted with grease fittings to make certain that they remain free and moving.

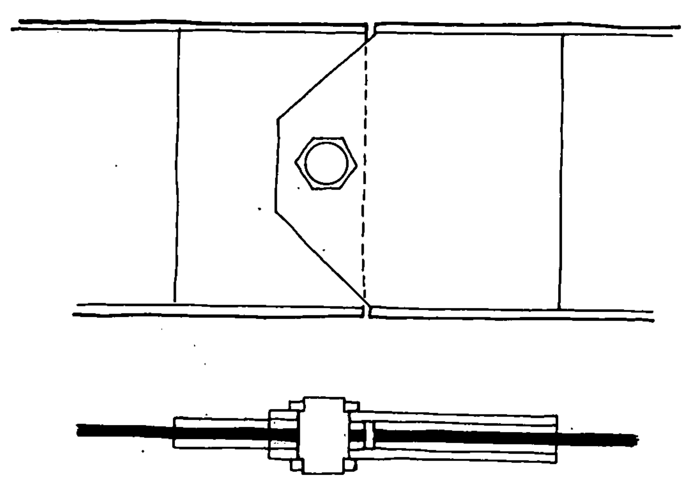


Figure 33. A no-moment pin joint in a plate girder; rotation only, no horizontal movement.

CHAPTER SIX

ELASTOMERIC DEVICES

In the search for a more satisfactory bridge expansion device, the desire has been for something with no moving parts that can freeze, nothing that can corrode or deteriorate, and something that does not require a lot of maintenance. Elastomeric pads (Figs. 34, 35, and 36) come close to fulfilling all of these qualifications. They have been in use for several decades, which is some assurance that their durability is real and not theoretical and that they may be expected to last for the life of the structure.

Elastomeric pads have few maintenance requirements; however, other conditions can cause them to fail. Poor quality is a prime cause of failure. Earthquakes can, of course, cause great difficulty, such as completely moving the pad from between two bearing surfaces without damaging the structure. Other failures have resulted from improper installation of the pad.

It is the promise of maintenance-free operation that has been the impetus for use of elastomeric pads. Pads also have the advantage of low initial cost and low installation cost. Thus, elastomeric pads have become extremely popular for all types of bridges to handle movements of 2 to 3 in. (50 to 75 mm); many are being used for even larger movements (see Fig. 37). Rotation is handled well by elastomeric bearings. It is claimed that each ½-in. (13-mm) layer of elastomeric pad can accommodate one degree of rotation.

Some concrete bridges are being built with elastomeric pads buried so far in the interior that they can not even be seen, let alone be accessible for repair. This represents a gamble, with the odds dependent on the quality of the pads and the assurance that they will serve satisfactorily. Where the quality is sure to be good, it then becomes less of a gamble and more of a situation in which there should not be problems. There is no doubt that the appearance of many bridges can be improved by hiding the bearing details and not leaving open spaces visible over abutments or piers. However, before this is done, there should be sufficient experience with pads and the designs in which they are used to be quite certain that no problems will develop.

Use of pot bearings has become popular in Europe. They perform functionally much like spherical bearings, but use of elastomeric material as the load-carrying element avoids the mechanical and corrosive difficulties that are common with metal spherical bearings. A pot bearing consists of a large round elastomeric pad confined by a heavy steel ring. Because the elastomeric material is confined, the unit loads can be increased considerably beyond the limiting values used when the pad may bulge out and decrease in thickness. The elastomeric material is able to handle rocking movements but not horizontal movements because of the confinement. Pot bearings have also been combined with stainless steel plates and TFE pads to produce a pot bearing with a horizontal movement potential.

The ability to support rocking loads eliminates the necessity of precise finishing of the bearing surfaces and other precision mechanical arrangements. The confinement also saves the elastomeric material from the damaging pressures that can result when a rocking load shifts to the edge of an unconfined pad. Although the material can squeeze around within the confining ring, it can not squeeze out or bulge on the edges regardless of the angle of the load application. A pot bearing can be designed to support quite a large load without critical concern for the angle of the load.

A sliding pot bearing is illustrated in Figure 38. The elastomer is confined within a steel cylinder, and the load is applied through a close-fitting circular plate, which acts like a piston. In fact, the elastomer has been found to act like a fluid under the load, distributing the pressure equally over the base with rotations up to 1:50. The stainless steel plate slides on the TFE to accommodate expansion and contraction. Figure 39 shows applications in which pot bearings were used at the top of single-column bents.

An interesting adaptation of the pot bearing is available in the proprietary Wabo-Fyfe bearing. It has some of the features of a pot bearing and uses a cast-polyurethane elastomer element. It can also be combined with a stainless steel plate and a TFE pad to allow either unidirectional or omnidirectional movement (Fig. 40).

At least one state uses what is essentially a steel pot bearing. They use a round steel bearing machined spherically on the bottom that fits into a round hole with a matching concave bottom in a large bearing shoe. They have also used the same bearing with the lower shoe mounted on a rocker nest that gives the bearing unidirectional movement.

DESIGN

Elastomeric Bearing Stresses

The average unit pressure on unconfined elastomeric bearings should not exceed 800 psi (5 500 kPa) under a combination of dead load plus live load, not including impact. The average unit pressure due to dead load only should not exceed 500 psi (3 400 kPa). When dead load plus live-load uplift reduce the average pressure to less than 200 psi (1 400 kPa), the bearing should be secured against horizontal crawling, preferably by positive attachment to the top surface or to the top and bottom surfaces. When secured to the top and bottom surfaces, the bearing may be subject to momentary light tension (AASHTO 1.12.2).

The initial compressive deflection in a plain elastomeric bearing or in any layer of a laminated bearing under dead load plus live load not including impact should not exceed $0.07\,t$ ($t =$ average thickness of a plain pad or thickness of any layer of a laminated pad). The deflection can be determined from a plot (see Figs. 41 to 44) showing the t 4/5/4

4/5/4
333288 PR
AN EVALUATION OF BRIDGE FIBERGLASS AND STEEL REINFORCED ELASTOMERIC
BEARING PADS
INVESTIGATORS: Stoker, JR
SPONSORING ORG: California Department of Transportation; Federal Highway
Administration Structures and Applied Mechanics Division
PERFORMING ORG: California Department of Transportation Transportation
Laboratory 5900 Folsom Boulevard Sacramento California 95819
SUBFILE: HRIS
CONTRACT NO: F81TL13; HP&R
PROJECT START DATE: ND
PROJECT TERMINATION DATE: 8206
Develop thru specific physical tests compressive stress-vs- strain
relationships, ultimate strength and compressive creep characteristics, and
determine realistic upper stress limits to be used by designers.

DESCRIPTORS: BRIDGE BEARING PADS; COMPRESSIVE STRENGTH; CREEP PROPERTIES
ELASTOMERS; FIBER GLASS; GENERAL MATERIALS; RESEARCH PROJECT; STEEL
REINFORCEMENT; STRESS STRAIN RELATIONS; ULTIMATE STRENGTH
?t 4/5/7

4/5/7
208911 DA
TESTS ON FIVE ELASTOMERIC BRIDGE BEARING MATERIALS
Aldridge, WW; Sestak, JJ; Fears, FK
Highway Research Record, Hwy Res Board 1968 No 253, pp 72-83, 9 FIG, 3
TAB, 14 REF
SUBFILE: HRIS
solid, bonded, and laminated elastomeric bearing pads made of neoprene,
butyl, hypalon, ept, and chlorobutyl with shape factors ranging from one to
six were subjected to a series of three specific tests to determine their
respective load- deformation characteristics. Compression-deflection tests
were conducted to determine short-time load-deflection responses for solid
bonded and laminated pads placed between bearing surfaces of
concrete-and-concrete, concrete-and- steel, and steel-and-steel. Additional
vertical deflections due to static creep in the pad materials

[illegible] were measured over periods ranging from one to
Investigations were made to determine the effects of
(loaded in
repetitive reversed
horizontal shear forces acting on bearing pads loaded by
constant vertical
compressive force. Neoprene, butyl, ept, and chlorobutyl are
recommended
for use as bridge bearing pads. The only material rejected
(hypalon) as a
result of the tests also failed to meet AASHO materials
specifications.
Bonded and laminated pads are recommended where economically
practicable.
The effect of contact surface type, in which friction
provided the
restraint, appeared to be insignificant for normal surface
conditions
except in the case of short-time deflections. Further
suggestions include
the need of allowance for static and dynamic creep. /author/
DESCRIPTORS: BEARING TESTS; BOND; BRIDGE BEARING PADS;
BUTYL RUBBER;
COMPRESSIVE STRENGTH TESTS; CONTACT AREA; DEFLECTION TESTS;
DEFORMATION;
ELASTOMERS; LAMINATES; LOADS; NEOPRENE; STRUCTURES DESIGN AND
PERFORMANCE;
TESTING
?t 4/5/9

4/5/9
207703 DA
BEHAVIOR OF ELASTOMERIC BEARING PADS UNDER SIMULTANEOUS
COMPRESSION AND
SHEAR LOADS
Nachtrab, WB; Davidson, RL
Highway Research Record, Hwy Res Board 1965 No76, Pp83-101,
15FIG, 1TAB,
5REF, 2APP
SUBFILE: HRIS
a study of elastomeric bearing pad performance is presented.
This study
was conducted on laboratory-size pieces, but under
conditions which
approached as nearly as feasible the cyclic shear
conditions found on
actual structures rather than the initial shear conditions
of currently
published investigations. It is shown that the current
definition of shear
modulus is not applicable to elastomeric materials. A simple
formula is
developed and the constants determined by which A

satisfactorily close
approximation of the stress/strain curve can be reconstituted
mathematically. The parameters that affect such curves were found to be
testing rate, degree of strain, and previous deformation history of the
sample. Other parameters, such as grain direction and shape factors of less
than unity, are suspected of affecting these curves, but present study was
not conclusive. With A knowledge of the effects of these parameters and a
stress/ strain curve established by a standard procedure, it is possible to
compute pier shear forces as the engineering problem dictates. /author/

DESCRIPTORS: BEARING; BEARING PADS; COMPRESSION; COMPUTATIONS;
DEFORMATION; DEVELOPMENT; ELASTOMERS; FORMULAS; LABORATORY TESTS;
MATHEMATICAL ANALYSIS; PIERS; RATE; SHEAR; SHEAR FORCES; STRAIN RATE;
STRESS STRAIN CURVES; STRUCTURES DESIGN AND PERFORMANCE; TESTING

?t 4/5/11

4/5/11

163054 DA

BRIDGE BEARINGS

NCHRP Synthesis of Highway Practice N41 62 pp 48 Fig. 8 Tab. 3 App.

AVAILABLE FROM: Transportation Research Board Publications Office 2101
Constitution Avenue, NW Washington D.C. 20418

SUBFILE: HRIS; RRIS

This is a state-of-the-art report on precedures for design, fabrication,
construction, and maintenance of bridge bearings. Performance records for
currently used expansion devices are reviewed. The sliding device includes
lubricants between surfaces, lead sheets between plates, self lubricated
bronze plates, and polytetrafluoroethylene (TFE) sliding on stainless
steel. Rolling devices, such as roller nests, larger rollers, single
rollers, segmental rockers, and pinned rockers are examined. Linkage
devices are used between girder where no movement is to be transmitted.
Elastomeric bearing pads are quite successful, they have no moving parts to
freeze, nothing to corrode, and have little or no maintenance

requirements.
Routine maintenance of bridge bearings should be directed towards keeping
the bearings clean and free of water, salt, and debris. Recommendations
include designing a bridge with a few movable bearings as possible;
bearings should be designed to require a minimum of maintenance; provisions
should be made so that the bridge may be jacked up and the bearings
adjusted or replaced; material quality is important in elastomeric
bearings; inspection of bridge bearings should be included as part of the
regular bridge inspection program. Sponsored by the American Association of
State Highway and Transportation Officials in cooperation with the Federal
Highway Administration.

DESCRIPTORS: BEARINGS; BRIDGE BEARINGS; BRIDGE DESIGN; BRIDGE MAINTENANCE
; BRIDGE REPAIRS; CONSTRUCTION; DESIGN CRITERIA; ELASTOMERS; EXPANSION;
GENERAL MATERIALS; GIRDERS; LUBRICANTS; MAINTENANCE; MAINTENANCE, GENERAL;
PLATES; RIGHT OF WAY; ROLLERS; STATE OF THE ART STUDIES; STRUCTURES DESIGN
AND PERFORMANCE
?

relationship of shape factor, load, and durometer hardness of the elastomer under consideration. Compounds of 70 durometer should not be used in laminated bearings (AASHTO 1.12.2). Figure 45 also shows the effect of temperature on modulus of elasticity in shear for the various hardnesses.

Design Criteria

1. The thickness of the pad shall not exceed ⅕ the width for plain bearings nor ⅓ the width for laminated bearings; thickness shall be not less than twice the total horizontal movement. Minimum thickness should be 1 in. (25 mm).

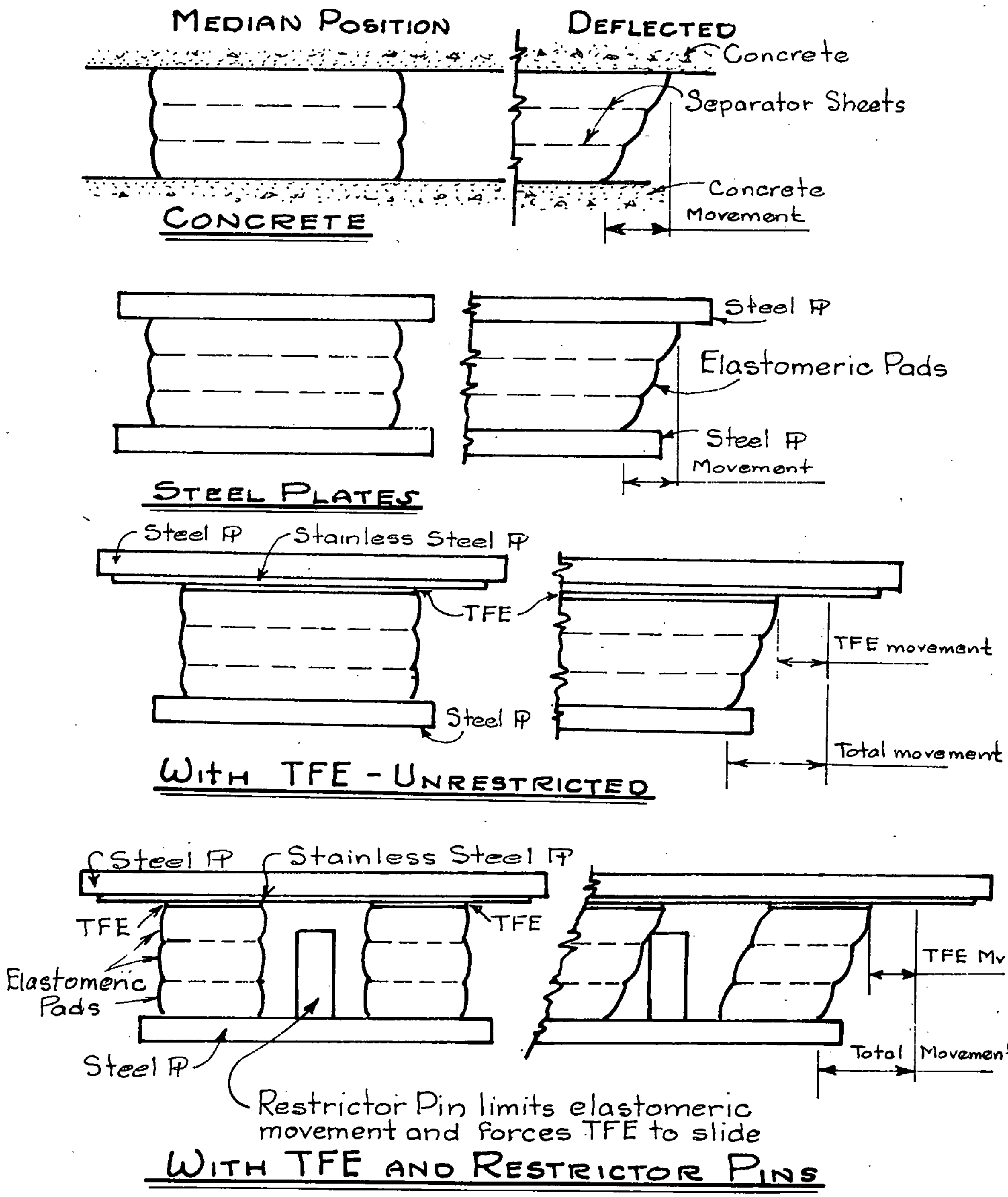


Figure 34. Elastomeric bearing pads.

2. The initial vertical deflection (including the effect of rotation) shall not exceed 15 percent of the uncompressed thickness of the pad. Minimum pressure on the pad shall be not less than 200 psi (1 400 kPa).

3. Shear Force $= \dfrac{\text{Modulus} \times \text{area} \times \text{movement}}{\text{Pad thickness}}$ shall not exceed 1/5 the dead load.

4. The temperature range to be provided for should be determined for each individual structure from the local climatic conditions.

Other Design Parameters

There is sometiems a temptation to use excessive areas of elastomeric pads. Where there is a wide bearing area, the designer may be inclined to cover the entire area with pads. This should not be done. Pads generally should not exceed 30 in. (760 mm) in maximum dimension. If larger pads are required, provision should be made for placing them in smaller segments. When several smaller pads are to be used to provide the bearing area, a note, such as the following,

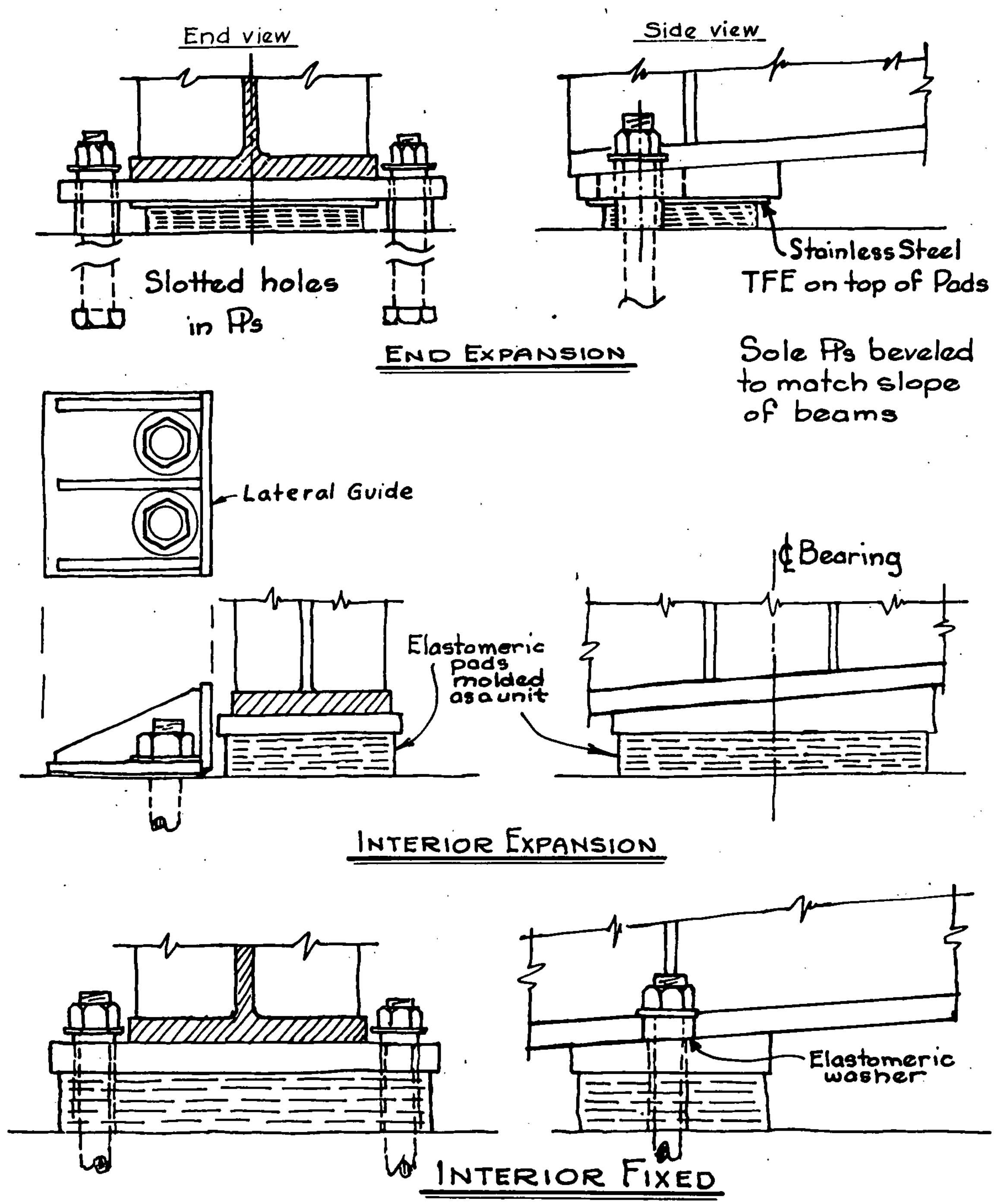


Figure 35. Elastomeric pads with steel beams.

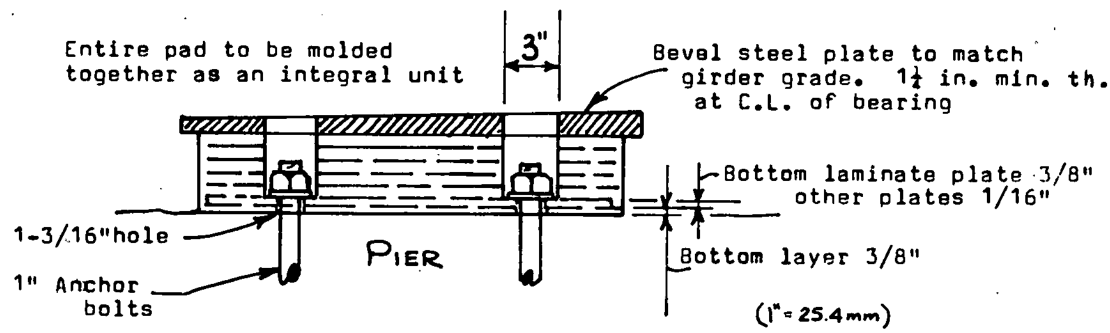


Figure 36. Miscellaneous elastomeric pad details.

may be used on the plans: "Elastomeric pads may be made up of not more than [specify number] separate sections, each having approximately the same plan area." Where no pad is required in the bearing area, the space may be filled with some inactive expanded material such as polystyrene.

In order to reduce bulging and to control movement, the thicker pads must be laminated. Single pads can be used up to 1 in. (25 mm), but if thicker than 1 in., the pads should be made up of laminations preferably not over ½ in. (13 mm) thick. [Some states use a ⅝-in. (16-mm) lamination.] An inelastic membrane must be provided between the laminations. The make-up and placing of these membranes is discussed in the following section.

MATERIAL

The success of an elastomeric bearing pad depends vitally on the quality of its material. It can not be emphasized too strongly that if elastomeric pads are to be used, their quality must be specified and the specifications adhered to exactly. The inclusion of excessive additives and fillers to lessen the cost can only result in early failure.

The sole polymer in the elastomeric compound may be either virgin natural polyisoprene (natural rubber) or virgin chloroprene (neoprene) meeting the requirements of Tables 6, 7, or 8 and must be not less than 60 percent by volume of the total compound. The neoprene is generally preferred.

Although other hardnesses are still being used by some agencies, a durometer hardness of 55 ± 5 is the most generally used. Softer pads bulge too much and perform poorly because of excess internal movement; harder materials are not sufficiently flexible.

It is important to have very rigid specifications as to the

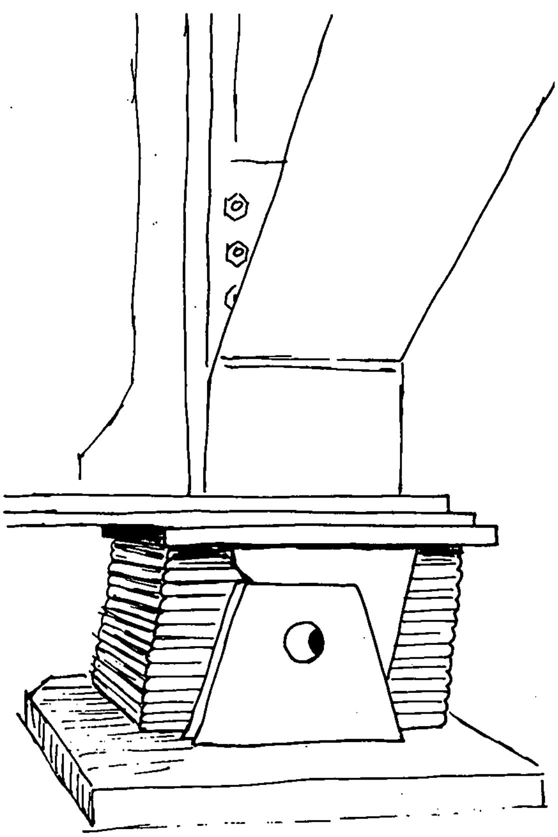


Figure 37. An elastomeric pad installation for large movements (European). Europeans use elastomeric pads for much larger movements than is commonly done in America. This pad has at least 16 laminations of approximately 0.5 in. (13 mm) each. Note the shear plate arrangement to keep the movement unidirectional.

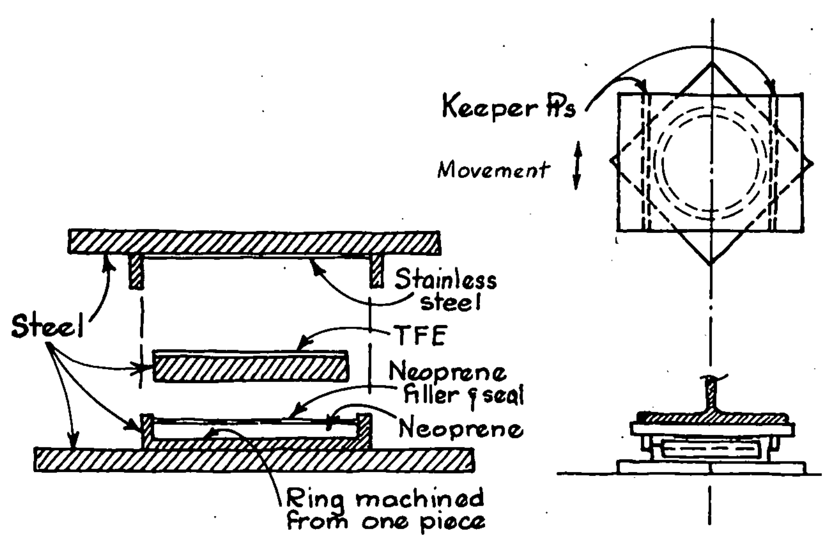


Figure 38. A sliding pot bearing.

composition of the elastomer as well as careful limits on the manner of its fabrication. In addition to the material specifications, tests should be specified so that the quality may be checked. (See Appendixes B and C.) Specimens tested for 10,000 cycles at 800 psi (5 500 kPa) and ½ t translation (t = pad thickness) should show no indication of deterioration of elastomer or bond between elastomer and metal or fabric reinforcement laminations.

A recent study in New Jersey indicates that current specifications and tests may not ensure uniform quality of elastomeric materials. (See Chapter Two.)

The contractor should be required to furnish a certification by the manufacturer that the elastomer and the fabric (if fabric is used in the elastomeric bearing pads furnished) conform to all requirements. The certification must be supported by a copy of the results of tests performed by the manufacturer upon samples of the elastomer and fabric used in the pads.

Random samples should be taken and checked to confirm the quality. The provision for sampling should be included in the contract so that additional pads can be furnished to replace those taken for testing.

When pads greater than 1 in. (25 mm) are called for, a manufactured, molded laminated pad is preferable to individual laminated pads stacked in the field. Provision must be made to hold the pads in the stack securely so that they remain in proper alignment.

Laminations

Pads 1 in. (25 mm) or less thick can be all elastomer or can be laminated. Pads thicker than 1 in. should be laminated. Laminated pads must consist of alternate laminations of elastomer and metal or elastomer and fabric separators bonded together. A separator must be used on both the top and bottom of the stack. These outside laminations can be either metal or fabric. The outside faces and edges of metal laminations must be coated over with elastomer to ⅛ in. (3 mm) in thickness.

Metal laminations should be rolled mild steel sheets not

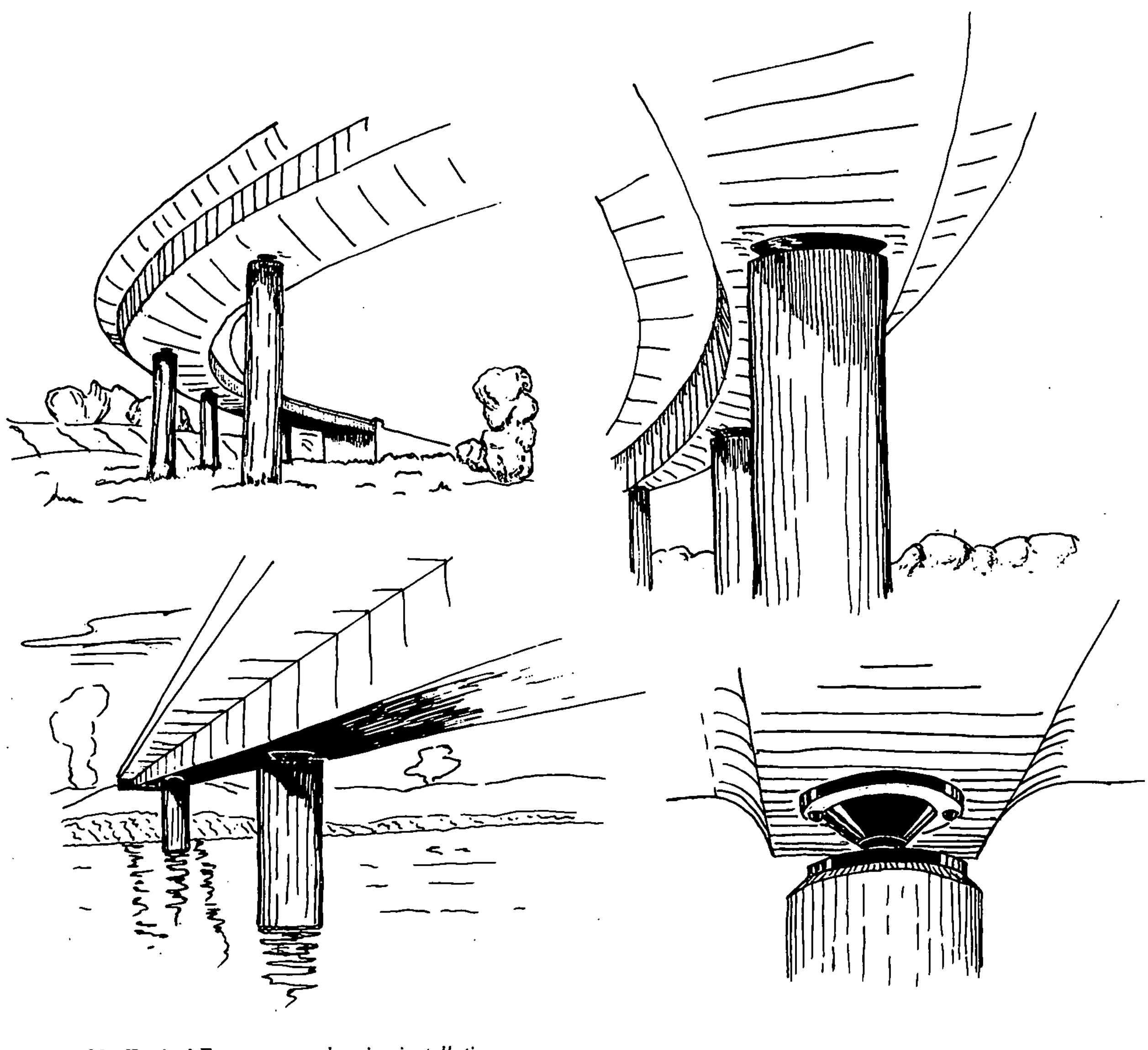


Figure 39. Typical European pot bearing installations.

TABLE 6

SPECIFICATION FOR NATURAL RUBBER IN BEARING PADS (AASHTO 2.25.2)

TEST	ASTM DESIGNATION	REQUIREMENT 50 DURO	60 DURO	70 DURO
PHYSICAL PROPERTIES:				
Hardness	D 2240	50±5	60±5	70±5
Tensile strength, min. psi	D 412	2500	2500	2500
(kPa)		(17,000)	(17,000)	(17,000)
Ultimate elongation, min. %		450	400	300
HEAT RESISTANCE:				
Change in durometer hardness, max. points		+10	+10	+10
Change in tensile strength, max. %	D 573 70 hr at 158 F (70 C)	-25	-25	-25
Change in ultimate elongation, max. %		-25	-25	-25
COMPRESSION SET:				
22 hrs at 158 F (70 C), max. %	D 395 Method B	25	25	25
OZONE:				
25 pphm ozone in air by volume, 20% strain, 100 F ±2 (38 C ± 1), 48 hrs.	D 1149	No cracks	No cracks	No cracks
Mounting procedure	D 518, Procedure A			
ADHESION				
Bond made during vulcanization, lbs/in.	D 429,B	40	40	40
(N/mm)		7	7	7
LOW TEMPERATURE TEST:				
Brittleness at -40 F (-40 C)	D 746, Procedure B	No failure	No failure	No failure

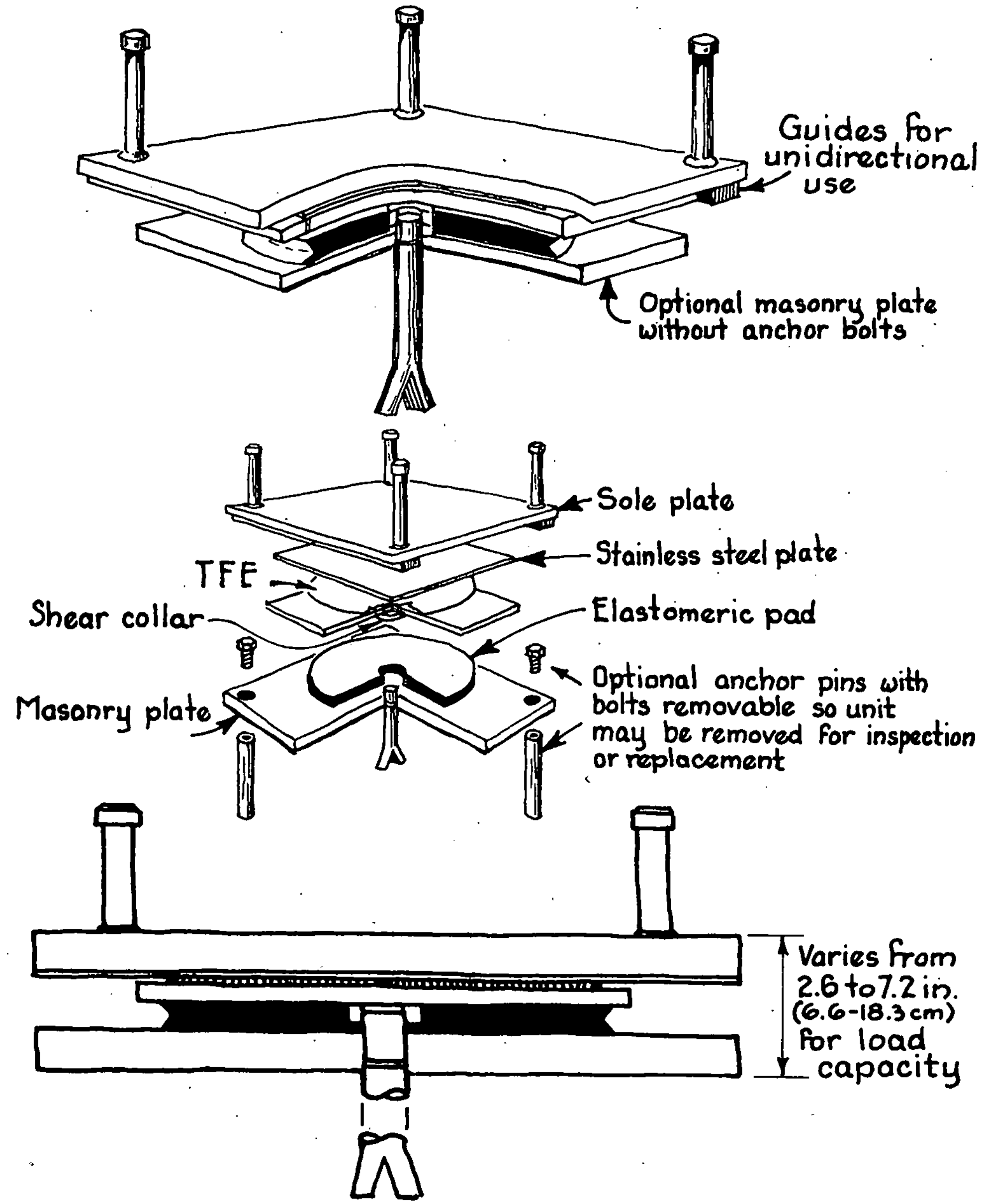


Figure 40. A high-load bearing with both pot and sliding characteristics (Wabo-Fyfe bearing).

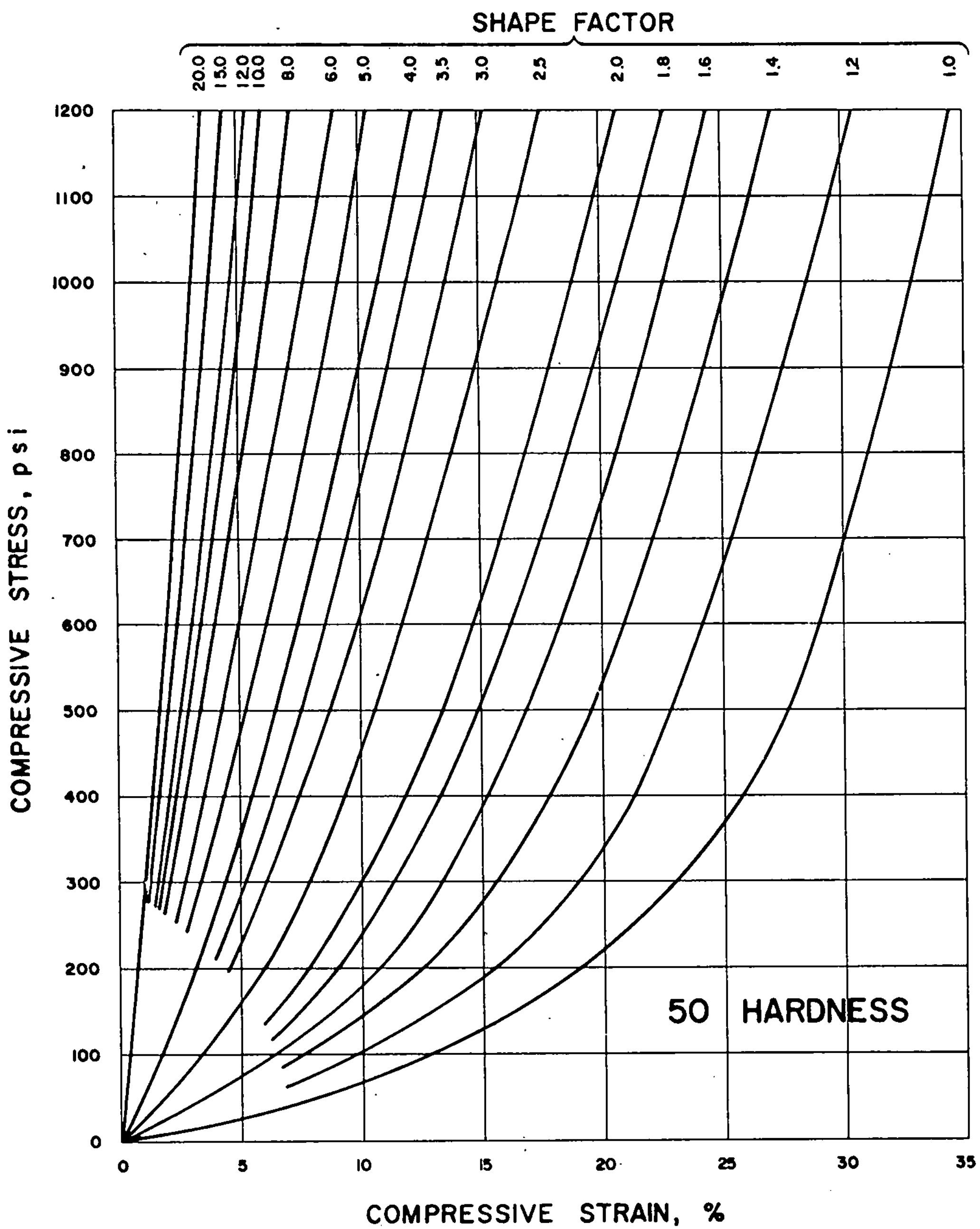


Figure 41. Elastomeric bearing performance (50 durometer) (adapted from NCHRP Project 12-9). Shape factor is defined as the area of the loaded face divided by the side area free to bulge.

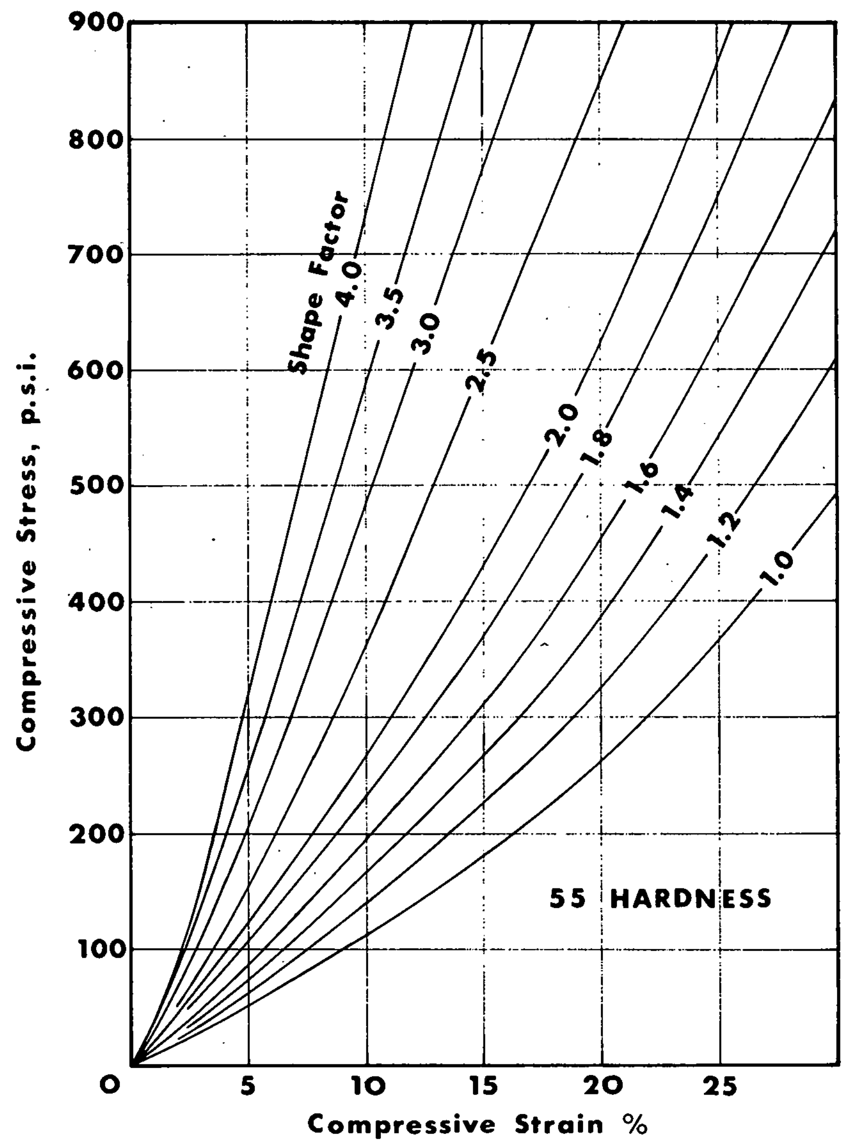


Figure 42. Elastomeric bearing performance (55 durometer).

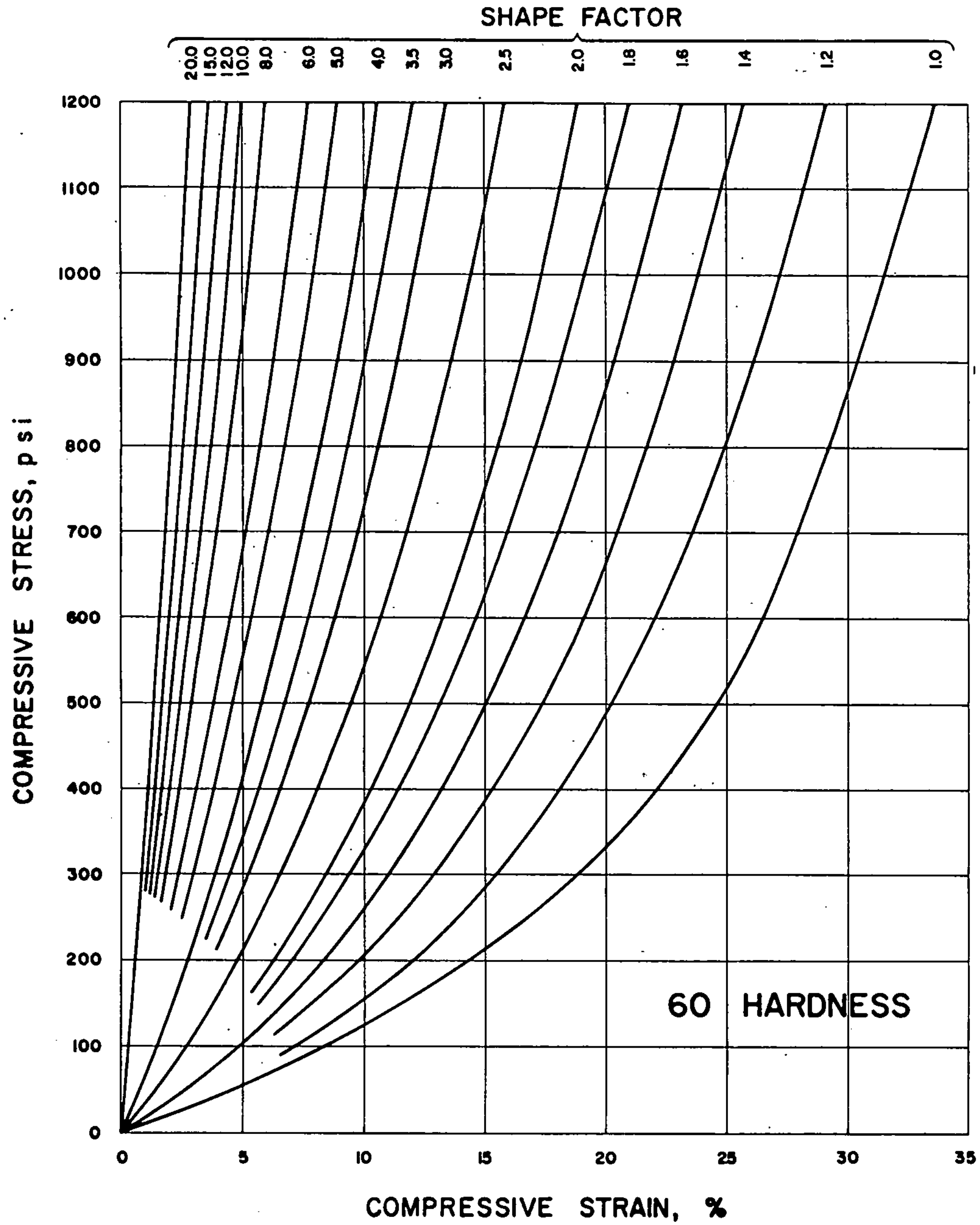


Figure 43. Elastomeric bearing performance (60 durometer) (data from NCHRP Project 12-9; adapted by California Dept. of Transportation).

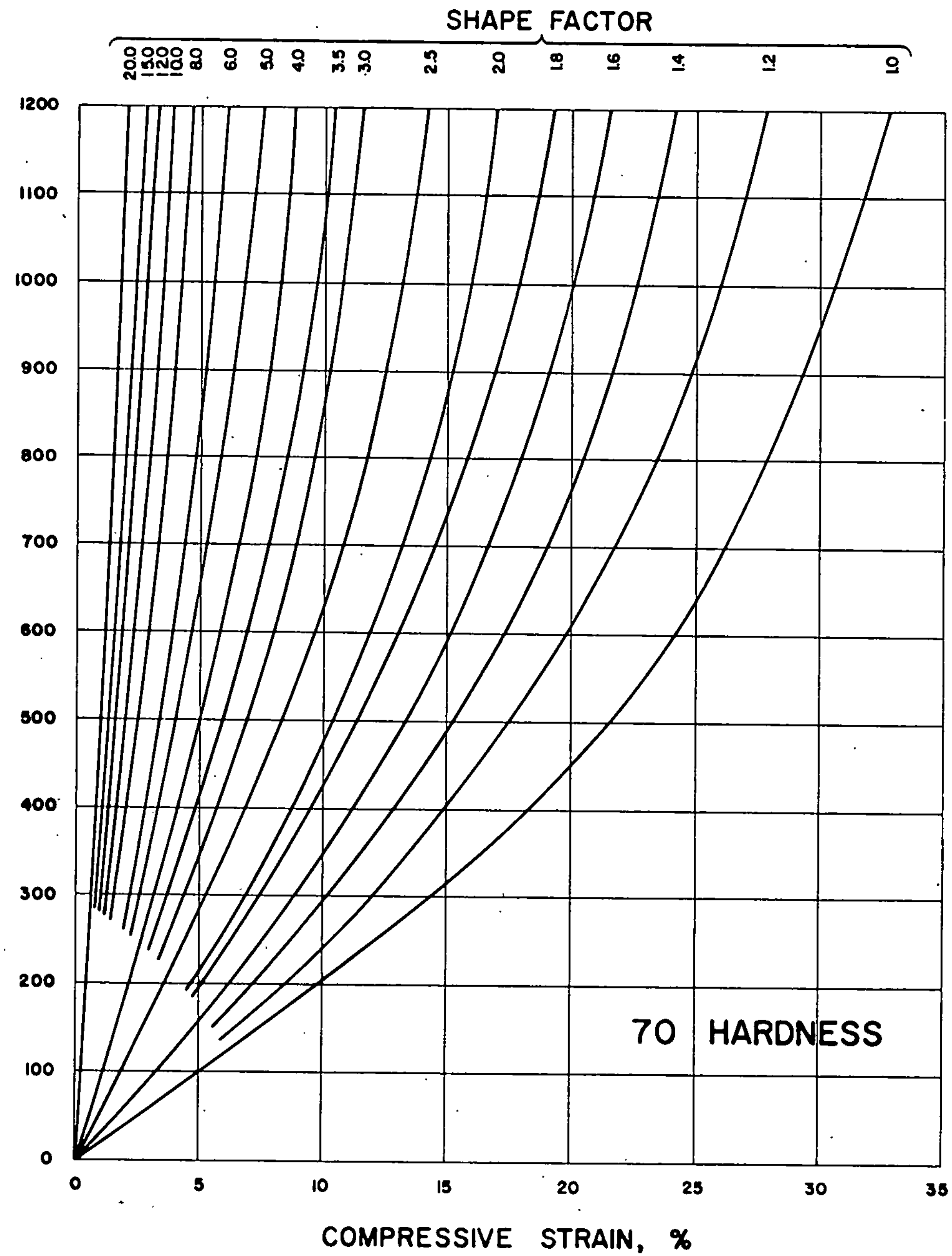


Figure 44. Elastomeric bearing performance (70 durometer) (data from NCHRP Project 12-9; adapted by California Dept. of Transportation).

TABLE 7

SPECIFICATION FOR NEOPRENE IN BEARING PADS (AASHTO 2.25.2)

TEST	ASTM DESIGNATION	REQUIREMENT 50 DURO	60 DURO	70 DURO
PHYSICAL PROPERTIES:				
Hardness	D 2240	50 ± 5	60 ± 5	70 ± 5
Tensile strength, min. psi (kPa)	D 412	2500 (17,000)	2500 (17,000)	2500 (17,000)
Ultimate elongation, min. %		400	350	300
HEAT RESISTANCE:				
Change in durometer hardness, max. points	D 573 70 hr at 212 F (100 C)	+ 15	+ 15	+ 15
Change in tensile strength, max. %		- 15	- 15	- 15
Change in ultimate elongation, max. %		- 40	- 40	- 40
COMPRESSION SET:				
22 hrs at 212 F (100 C), max. %	D 395 Method B	35	35	35
OZONE:				
100 pphm ozone in air by volume, 20% strain, 100 F ± 2 (38C ± 1), 100 hrs.	D 1149	No cracks	No cracks	No cracks
Mounting procedure	D 518, Procedure A			
ADHESION:				
Bond made during vulcanization, lbs/in. N/mm	D 429, B	40 7	40 7	40 7
LOW TEMPERATURE TEST:				
Brittleness at - 40 F (- 40 C)	D 746, Procedure B	No failure	No failure	No failure

TABLE 8

SPECIFICATION FOR 55 DUROMETER NEOPRENE IN BEARING PADS (CALIFORNIA)

TEST	ASTM DESIGNATION	REQUIREMENT 55 DURO
PHYSICAL PROPERTIES:		
Hardness (Type A)	D 2240	55 ± 5
Tensile strength, min. psi (kPa)	D 412	2250 15,000
Elongation at break, min. %	D 412	350
Tear strength, min. psi (kPa)	D 624 Die C	180 1200
COMPRESSION SET:		
22 hrs @ 158 F (70 C), max. %	Method B	25
OZONE:		
Resistance 20% strain 100 hrs @ 100 F ± 2 (38 C ± 1)	D 1149 Except 100 ± 20 parts/ 100,000,000	No cracks
LOW TEMPERATURE TEST:		
Stiffness max. psi (kPa) Young's modulus at-30 F (-34 C)	D 797	5000 (34,000)
Brittleness 5 hrs @ -40 F (-40 C)	D 736-54T	Passed
ACCELERATED AGING:		
70 hrs at 212 F (100 C)	D 573	
Tensile strength, max.change %		± 15
Elongation at break, max. change, %		- 40 (but not less than 300% total elongation of the material)
Hardness, points, max. change		+ 10

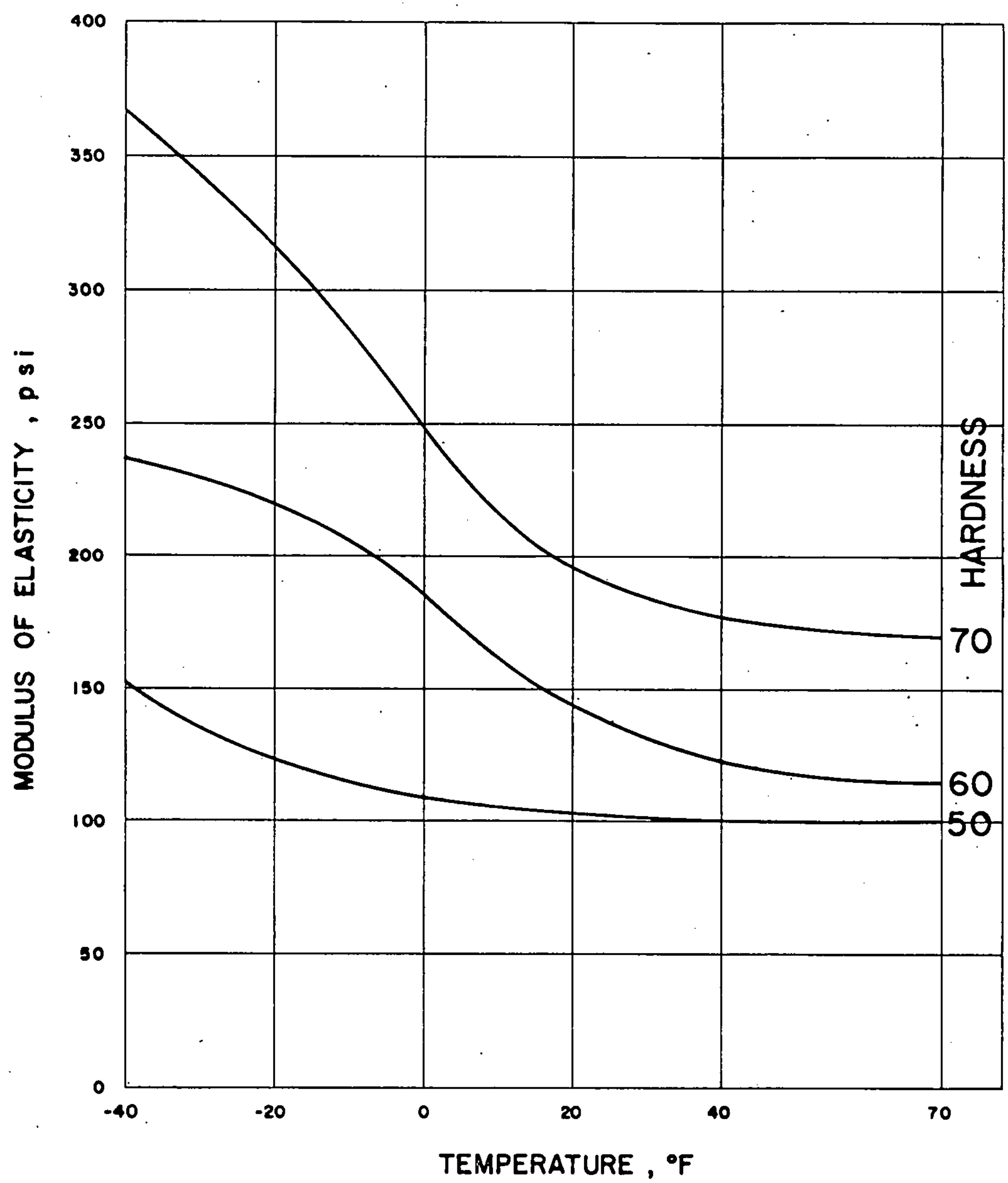


Figure 45. Variation of modulus of elasticity in shear, G_{avg}, with temperature (data from NCHRP Project 12-9; adapted by California Dept. of Transportation).

less than 20 gage [0.0359 in. (0.91 mm)] in thickness, with thicker sheets for thicker layers. Fabric laminations should be of glass fibers. They should be woven of 100 percent E-type yarn with continuous fibers. The fabric should have 25 threads/in. (1 thread/mm), woven in either a crow-foot or eight-harness satin weave. Each ply should have a breaking strength of at least 800 lb/in. (140 N/mm) width when a 3 × 36-in. (75 × 910-mm) sample is tested on split-drum grips. There should be a single layer of fabric at both top and bottom and interior membranes should be double ply. The bond between the double plies should have a minimum peel strength of 20 lb/in. (3.5 N/mm).

FABRICATION

Several states used elastomeric pads with enthusiasm when they were first introduced. Pads possessed many advantages that solved troublesome local situations. Pure elastomer was purchased from a large producer and the pads were manufactured mainly by local fabricators. However, quality standards had not been established and the material was often adulterated with fillers and other materials to the point that the pads would not stand up under use. Failures were rapid and widespread. Repairs were so costly and the whole experience so discouraging that a number of states abandoned the use of elastomeric pads entirely. It took a number of years to prove that exacting quality specifications and controls are imperative and that pads of good quality would perform as desired.

There are several methods of fabricating elastomeric pads. The early pads were made with metal separators glued between the laminations. Steel was usually used, and the parts exposed to the air corroded. The glue was not of sufficient strength and pulled apart. The solution seemed to be to hot-mold the pads to finished size during manufacture so as to have a protective coating of the elastomer over the edges and sides of the metal separators. This need for covering the edges precluded making the pads in larger sheets and then sawing them to size. There is a tendency for the saw to tear the elastomer away from the separator plate as it is sawed. In addition, the edges of the steel plate separators that have been sawed invariably rust.

To make possible the sawing of pads to size rather than having to mold each individually to its finished size, fabric separators were introduced in 1958 in California and found to be successful. The pads can now be manufactured in large standard sizes and then sawed to size to meet individual requirements. Special care in the selection and use of saws is necessary to make a smooth cut. Cutting must be performed to avoid heating of the material and to produce a smooth edge with no tears or other rough places to damage the material. If the edges of the pad are badly scratched or cut, these scratches and cuts become points of weakness and stress-raisers of sorts, and failure cracks may initiate in them. AASHTO specifications require cut edges to be at least as smooth as ANSI 250 finish.

The bond between elastomer and metal or fabric must be such that, when a sample is tested for separation, failure occurs within the elastomer and not between the elastomer and the metal or fabric.

Corners and edges of molded pads can be rounded at the option of the manufacturer. Radii at corners should not exceed ⅜ in. (9 mm); the radii of edges must not exceed ⅛ in. (3 mm).

Generally the plan dimensions of pads should be given in increments of 2 in. (50 mm); pads are usually manufactured in these increments.

Although elastomeric pads have an inherent capability for variation, fortunately, they are also less affected by small dimensional differences. Variations in thickness of an individual elastomer lamination should not exceed ⅛ in. (3 mm) from a plane parallel to the top or bottom surface of the pad. The total thickness of a pad must not be less than the thickness shown on the plans nor more than ¼ in. (6 mm) greater than that thickness. Variations of total thickness within an individual pad should not exceed ⅛ in.

There have been problems in making the fabric separators hold their position as a true plane. Immersed in a fluid elastomer without interior support, there is a tendency for the separators to sag and to become displaced; this has been largely overcome. Individual separators should not vary more than ⅛ in. (3 mm) from a plane parallel to either the top or bottom face of the pad. If the separators are out of position in the pad, their function of restraining the individual laminations can not be performed.

INSTALLATION

Seat Preparation

Whether or not the elastomeric pad is to be glued to its seat, the seat should be made smooth and level. If the pad

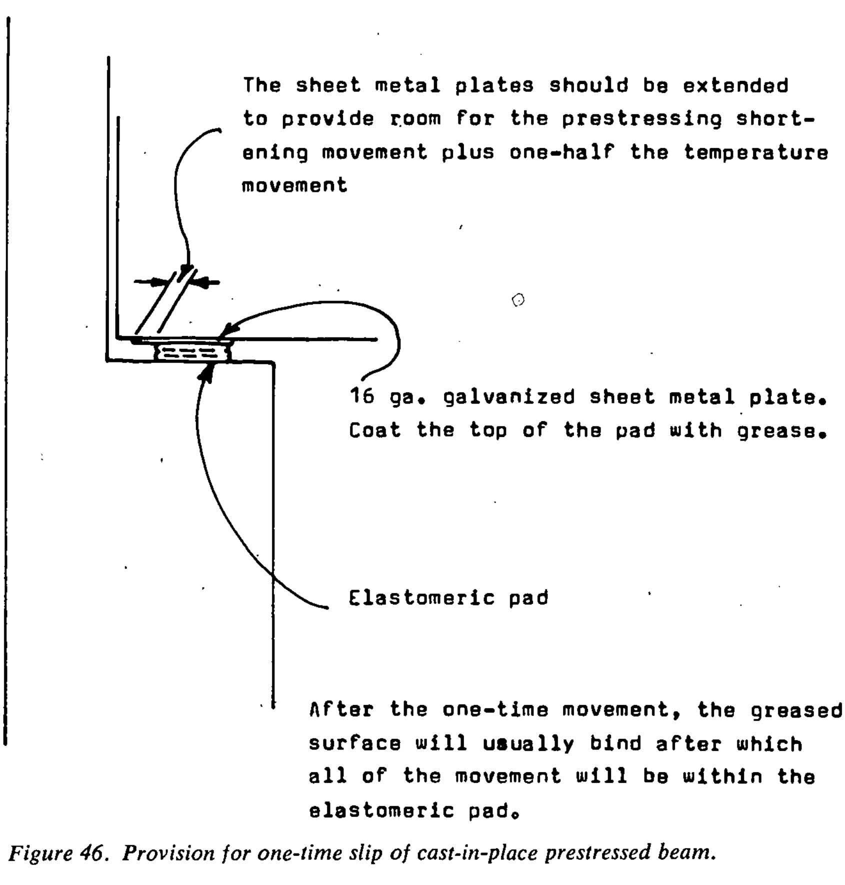


Figure 46. Provision for one-time slip of cast-in-place prestressed beam.

is to be set on concrete already placed and set, the surface should be prepared as carefully as it would be for seating a steel shoe. If the concrete is to be placed against the elastomeric pad while it is held in the forms, great care should be taken to see that the pad remains flat and level while the concrete is being placed. This may require temporary supports to hold it rigid and in position while the concrete is placed against the first side. Pads that are wrinkled, bent, twisted, or curved can not work properly.

In prestressed, cast-in-place concrete construction, there is the problem of the one-time slip during the stressing operation. This is often handled by placing a greased 16-gage (1.52-mm) galvanized metal plate on the top of the stack of elastomeric pads. The grease remains active until the stressing is completed and the superstructure makes its one substantial slip at the bearing. The grease then dries up or becomes dirty and that portion of the bearing freezes, leaving all subsequent movement to the stack of elastomeric pads, which is exactly what is intended (Fig. 46).

Concrete Placement

One of the chief construction difficulties with elastomeric pads is having the concrete properly and fully placed against both faces of the pad. This may sound simple; however, more than one failure has been traced after considerable work with a jackhammer to air voids under the pad.

Placing the concrete against the top surface is not difficult, but placing a full bearing of concrete where it must be worked or pushed up under an elastomeric bearing is not easy. This should be considered during the design. The area above and below a bearing is always one of dense reinforcing steel, making the concrete placement even more difficult. It is sometimes necessary for the lower concrete to be placed first so that the access is better. Holes can be provided through the bearing pads so that a check can be made to see that the concrete is fully in contact. This is not an isolated problem and deserves a great deal of attention. Based upon observation, it would seem likely that 20 percent of the underneath area of most cast-in-place bearings contain a void formed either by air bubbles or bleed-water pockets during construction.

Adhesives

There have long been discussions as to whether or not elastomeric pads should be firmly cemented on both sides. Experience would lead one to believe that the adhesive is not necessary on concrete surfaces. However, some designers feel that some restraint is desirable and therefore call for the pads to be cemented to steel bearing surfaces. The following describes the procedure to cement a pad to a steel girder:

> The steel plate surface is thoroughly sandblasted to assure a good bonding surface. If it is a single plate to which the pad is being glued, both sides of the plate should be treated to prevent warping. The elastomeric pad is also cleaned and lightly sanded to improve the bond surface after which the pad and plates are wiped with a cloth soaked in toluene to remove any traces of grease or dirt. The adhesive is then mixed and spread on both matching surfaces. After waiting 10 to 30 minutes, the surfaces are put together; the adhesion should be permanent.

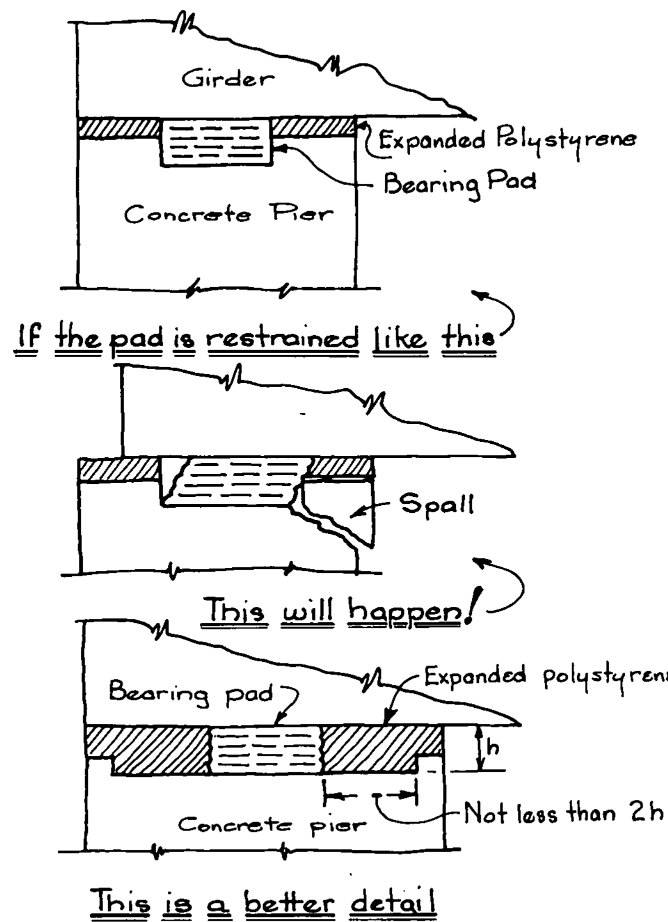


Figure 47. Restraining elastomeric bearings.

Elastomeric pads are sometimes glued to both surfaces when they are used between steel plates. If not, keeper plates should be provided to keep the pads in place.

When elastomeric pads are used between concrete surfaces, the concrete is usually placed against them without any adhesive. However, under violent movement, such as an earthquake, pads tend to "walk" out of position. In one case, a 6-ft (1.8-m) pad moved lengthwise and almost completely escaped from between the two bearing surfaces during a 12-second earthquake. It ended up hanging down the end of the abutment. Pads should be arranged so that there is a concrete restraining lip around them.

When a lip is cast around the pads, care must be taken not to hedge them in too closely. If the pads do not have room to swell and move back and forth, the concrete restrainers will be broken out (Fig. 47).

Under normal use, elastomeric pads usually do not show any tendency to walk, even without any glue or other restraining device. The glue and restrainers are merely safeguards against unusual conditions. It is common to require that pads be glued to the support when the dead load plus live-load-uplift pressure on the pad average less than 200 psi (1 400 kPa).

CHAPTER SEVEN

OTHER BEARING DEVICES

SPHERICAL BEARINGS

For complete freedom of movement, some designers have devised spherical bearings, using either a half-sphere or an entire ball. These are often used at the bottom or top of a column to prevent any bending moment getting into the column. The fact that they have not been widely used would seem to indicate that their success has not been overwhelming. They no doubt freeze easily and fail to function as planned. Nevertheless, bridges have been built with several spans and all columns resting on balls at the bottom. AASHTO specifications offer no guidance in this area although some foreign specifications have design formulas.

Spherical bearings can cause difficulty during erection. On a bridge with unrestrained spherical bearings at the top and bottom of the columns, each column must be externally supported during erection and the whole bridge (which resembles a house of cards) must be well supported until it is firmly tied to its abutments or to stiff intermediate piers that provide stability. Erection of such bridges is not easy.

CYLINDRICAL BEARINGS

The moment-free advantages of a spherical bearing have been realized to a material degree with the more practical cylindrical bearing. These may be half-cylinders, usually attached to the base of the column, or whole cylinders fitting into round slots both top and bottom. Sometimes the lower slot may be in concrete with a liner of sheet lead. The column can be steel or concrete and can either have a similar leadlined slot in its base or be rigidly attached to the cylinder. The aforementioned erection difficulties with spherical bearings also apply to cylindrical bearings. If the cylinders are several feet long, however, they have considerable lateral stability. These bearings were often used at the base of columns of rigid frame bridges when they first became popular 30 or 40 years ago.

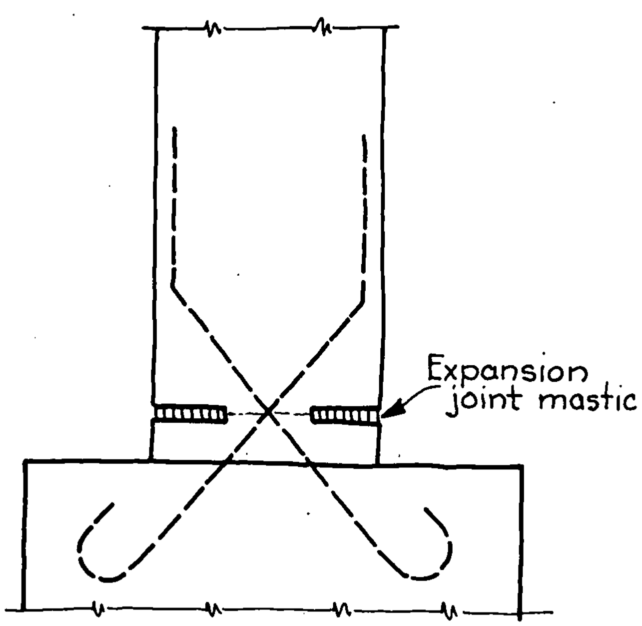


Figure 48. Concrete hinge at the base of a concrete column.

HYDRAULIC CYLINDERS OR DASH-POTS AND FLOATING DEVICES

Hydraulic cylinders and dash-pots are special bearings designed to solve some peculiar problem. There is little similarity or standardization among them. Their common fault is that they require almost perfect maintenance to perform properly. They can be an endless source of trouble.

Dash-pots were often used on movable bridges to cushion the shock of landing the swing or lift span. They invariably caused trouble and needed continuous maintenance and repair.

MOVABLE BRIDGE BEARINGS

Although it is not within the scope of this synthesis to exhaustively examine machine-type bearings that are used in movable bridges, it does seem worthwhile to note the differences that good bearings can make in a movable bridge.

For many years, vertical-lift bridges were designed with bronze bearings on the counterweight sheaves, and it was common to provide a 50- or 75-hp (37- or 56-kW) electric motor to raise and lower the span. When designers realized that most of this power was wasted overcoming friction in the system, a bridge with a lift span of about 200 ft (61 m) was designed with high-quality roller bearings. An electric motor of only 7½ hp (5.6 kW) on each tower top moved the bridge easily. This represented a major saving in energy and resulted in a smoothly operating structure. Combined with an electronic control system, it was possible to stand on the bridge and not be aware of its start-up or landing. Such smooth operation would also mean substantial maintenance savings. This is another case in which the application of the latest technology can result in material savings in bridge construction and maintenance.

CONCRETE HINGES

In concrete structures in which a hinge is desired at the base (or top) of a column, the hinge arrangement shown in Figure 48 can be used. It generally works very well so long as the movements are small.

CHAPTER EIGHT

RESTRAINING DEVICES

Various restraining devices are necessarily a part of the bearing system of a bridge. They generally fall into two categories: (a) devices to hold a bridge down and resist uplift and (b) devices to restrain expansion joints to prevent their being torn apart in an earthquake.

TIE-DOWN DEVICES

Cantilever anchor spans usually have to be tied down. On large structures, these tie-downs can be a chain of eyebars. On a smaller, continuous concrete structure, the end tie-down can only be long bolts through the elastomeric pads down into an anchorage in the pier. Although the tie-down can also provide the support bearing (as in the case of a long compression strut), the tie-down is often a separate device going through or around the normal bearing to secure against potential uplift.

RESTRAINERS THROUGH EXPANSION JOINTS

During the 1971 San Fernando, Calif., earthquake, the only earthquake in which a modern structure was near the center of the disturbance, one of the principal causes of failure was expansion joints pulling apart. Consequently, standard pratcice in earthquake-prone areas now is to supplement the expansion bearings with restrainers that limit the distance the two sections can come apart. Several systems are in use. Some are easier to use in initial construction; others are better for retro-fitting an existing bridge.

Continuous Cable

After the girders have been placed but before the deck is put on, a continuous cable is wound around anchors on each side of the joint until there are enough strands to provide the required restraint. The slack and stretch in the cable allow for normal movement but, should a major movement occur, the cables prevent any wide separation.

Prestressing Units

In this system, a number of prestressing strands are united into one restrainer. Crushable material, such as styrofoam, is placed under the bearing washers to allow the desired movement; however, when movement exceeding this occurs, the cables restrain it.

Large Bolts

Bolts, 4 in. (100 mm) or larger, are installed in a manner similar to prestressing units. Excessive movement brings the bolts' full strength into play.

CHAPTER NINE

MAINTENANCE

ROUTINE MAINTENANCE

Regular bridge-bearing maintenance should be directed toward keeping the bearings clean and protecting them from water, salt, and debris. Cleaning methods depend on the type of bearing. If compressed air is available, it can be used to blow debris away from the bearings. Hoses and water are often used. A small garden hoe is a good tool for pulling debris from pier tops. On older timber trestles, the hoe can be used to scrape the dirt from the tops of the caps between the stringers. No matter what is required, bearings should be kept clean. If bearings are provided with grease fittings, either to lubricate moving parts or merely to keep a space full of grease so that dirt can not penetrate, they should not be neglected.

Some bearings are not accessible. Designers like to enclose them to improve their appearance. This can mean that the bearings will be left untended because of the difficulty in removing the housing to inspect them. Regardless of the difficulty involved, bearings should be regularly inspected and cleaned.

Other than their exposed parts, hanger joints in steel girders and eyebar joints in large trusses are virtually impossible to inspect. The pins are hidden so that their condition can not be seen. Sometimes provisions are made for greasing with a pressure gun. Even though grease may not be of much importance in combatting friction, it does fill in all the available spaces and keep dirt and moisture out.

Pins sometimes freeze in their holes. The trouble can usually be eliminated by removing the pin and replacing it with one with grease slots and a grease fitting. Pushing new grease into the slots at regular intervals tends to expel the dirt and old grease and to keep the surfaces from binding.

Salt, water, and dirt are, no doubt, the main enemies of an expansion bearing. Therefore, a primary maintenance effort should be made to keep these destructive elements away from the bearing; this can usually be accomplished through an adequate sealing of expansion joints (a problem area all its own).

If the joints can not be effectively sealed to prevent any salt-laden water from penetrating the bearing, the bearing should be shielded to deflect the water elsewhere. If the designer was not farsighted enough to provide means for protecting and cleaning a vulnerable bearing, the maintenance employee must use ingenuity to keep the bearing clean and dry. A clean, dry bearing has a fair chance of survival. A wet, dirty one is almost certain to fail and cause trouble.

A good maintenance inspector has an intuition for what looks "right." Often some serious trouble has been caught early, because of an alert inspector. The inspector should be alert for cracks under bearing plates, perhaps indicating a freeze up. There should be evidence that all parts are moving as designed. It is helpful in cases of doubt to install telltales, which scratch on a metal plate to show what total movement a joint is experiencing. This method can identify frozen joints and situations in which too much movement is being thrown to a single joint in a series.

Rockers should be leaning back on a hot day and leaning forward on a cold one. Similarly, expansion joints should be narrow on a hot day and wide on a cold one. Both rockers and rollers should be aligned in the proper direction. If lugs shear off, rockers can turn at an angle to their proper line of operation and cause problems. They should also be free of rust or corrosion.

Elastomeric pads are often far inside the superstructure and, therefore, can not be inspected. The roadway should be checked for level riding across an expansion joint. If a bump develops, it may indicate that there is trouble with the bearing. If the pads are visible, they should be carefully inspected. There should be slight bulges in each lamination as the loads push the elastomer out. These bulged faces should be smooth with no checks or cracks. Poor-quality material often develops a crack along the point of greatest bulge. These cracks work into the pad until it is ruined.

There should also be plenty of room for the pads to work back and forth. If the restraining lips of concrete around the pad are too restrictive, the concrete will break away and restraint will be lost. Pads of sound design and quality that are properly installed need very litle maintenance.

Maintenance employees should never assume that because a bridge is new, there can be no problems. New bridges may have more problems than older ones. When a bridge has been in service for five years with no observed difficulties, some degree of complacency is allowable, but until then there is always the possibility of a serious defect showing up under use.

INSPECTION AND REPORTING

Adequate maintenance records for bridges are second only in importance to the inspection itself. Any agency having the responsibility for the maintenance of even a few structures should have a system whereby the structures are regularly inspected and their condition completely reported. Adequate reports should be kept on each structure beginning with its construction plans and financing and covering everything that has happened to the structure during its lifetime. The importance of such records seems obvious; unfortunately there are many agencies across the country with responsibility for structures that have neither a regular inspection procedure nor adequate records of the structure's physical characteristics or its capacity. It seems that no careful inspection is made until a break or a sag is reported. It is through such neglect that the poor state of bridge bearings develops. If no one ever looks at a bridge bearing or takes the trouble to clean it, it is only a matter of time until it is completely clogged with dirt and debris, rusted, and frozen.

Therefore, good records should be kept of every structure. Each inspection should be carefully noted in the records with an account of what was found, what was done, and what future condition may require more frequent inspection. Even if an inspection is made and everything is found to be in perfect condition, it should still be noted. Some records only show what went wrong and what was spent to fix it. This is not enough. There is real virtue in publicly demonstrating a continuing interest and making regular inspections of the structures.

PROBLEMS AND REASONS FOR FAILURE

Freezing

Bearings are provided to enable the structure to move as it changes its dimensions as a result of changes in temperature and other causes. The primary failure is that the bearing does not perform; it freezes or locks up so that no movement is possible. This throws the stress back into the structure, overloading some element and causing a failure.

The easiest to visualize is the failure of a roller nest. The classic roller nest is one consisting of a number of 1½- or 2-in. (38- to 50-mm) rollers locked into a frame and moving between two horizontal plates. Dirt and water penetrate. The spaces are small, the roller action is blocked, and rust sets in. Oddly enough, the bearing continues to function after a fashion, with the plates shoving back and forth over the developing mass of rust. Eventually, the rollers disintegrate to the point that it is difficult to count how many there originally were (Fig. 11). As the grinding movement continues, the flaky rust is gradually expelled and the two bearing plates nearly come together. As the rollers rust, the superstructure settles and a bump develops. Someone usually discovers the condition before the bearing disappears. Because the flaky rust does provide the possibility for some movement, the bearing may not lock up. However, when a bearing does lock up, it can crack off the front of an abutment or pier or pull an abutment or pier out of plumb.

Any mechanical bearing can freeze. Some are more prone to freeze than others. In general, the "sliders" are more likely to freeze than the "rollers." Even where the tolerances are close (such as between sliding surfaces), dirt can penetrate; even a small amount of dirt can impede the action. Steel-on-steel plates do not have a good sliding ability and can soon gall each other and freeze. Grease on the surfaces is only a temporary solution, because the grease actually seems to attract dirt and hold it so that it can work in between the surfaces. Steel on bronze has a better coefficient; however, dirt also penetrates in this case unless the bearing is almost hermetically sealed. Even bronze and graphite surfaces eventually get dirty and bind if they are not kept clean. The TFE on stainless steel has a good record thus far, but without cleaning, this bearing type also fails in time. There have been many cases in which sliding plate bearings of every design have frozen and caused cracking or spalling of the bearing seats.

If a bearing fails or appears to lock up, it is prudent to see the way in which the bridge compensates for the failure. Something must move; the secondary failure may, possibly, be worse than the initial failure of the bearing.

Unequal Bearing Action

In a long bridge with several expansion joints, it is obviously the designer's intention that each joint should take its share of the total movement. Without actually freezing, some bearings naturally offer more resistance than others; it is possible that all of the movement for an entire bridge might be thrown into one moving joint with disastrous results. Of two movable bearings supposed to act in tandem, the one that moves the easiest will probably take all of the movement, unless prevented in some way. Therefore, provision must be made with bolts, ties, or movement limiters across the joint to prevent any one joint from taking more than its designed amount of movement and to force the excess movement to go to the other joints. If a long bridge had four joints, each of which might move 2 in. (50 mm) without limiting devices, the easiest moving joint would probably accept the whole 8 in. (200 mm) of movement. This might mean tearing that bearing apart and opening a considerable crack in the roadway. Thus, it is necessary to make provision to force each bearing system to perform as designed.

A common solution is the use of bolts across the joints with compressible material under one end so that the allotted movement is possible after which the bolt becomes tight and forces the movement to the next joint (Fig. 30). Three 1½-in. (38-mm) bolts across an expansion joint in a two-lane bridge would be sufficient. Ties of this sort are not to be confused with ties put across expansion joints to secure the joint from coming apart in an earthquake. Earthquake ties must be considerably stronger. In several cases three 1½-in. bolts have popped like bailing wire under earthquake forces.

Twisted Bearings

Rockers without pintle pins, linkage between the rocker and plates, or keeper plates often move to one extreme of their movement and then lock there and slide. If such a condition already exists, the bearing should be removed and keeper plates installed to force the rocker to act and remain in position.

For new work, a rocker should never be designed without pintle pins, gear teeth, or some positive linkage to prevent the rocker from gradually working out of place and either lying down or popping out.

Dirt and Failure

Dirt, salt, and water are the culprits in the failure of almost any mechanical bearing. Mechanical blockage and corrosion go hand in hand. Galvanizing is only a temporary (but worthwhile) respite from eventual trouble. Dirt penetrates and grinds everything away. The solution is to keep the bearings open and free so that wind can blow debris away or so that maintenance employees can brush dirt away with a broom, a stick, compressed air, or water (the last of which, presumably, will drain away quickly).

Wear on Pins

Pins that experience movement will wear. It can take a long time but metal does wear away. Few pins are provided with any means of lubrication and for many locations, the presence of grease would only attract dirt and increase wear. Hence the wear is to be expected after a long period of time and should be watched for. Worn pins or bearings should be either replaced or built up by welding and re-turned (or rebored). Larger pins, 6 in. (150 mm) and greater, probably do not experience enough wear to make replacement necessary within the life of the bridge.

Failure in Skewed and Curved Bridges

Skewed bridges present a problem to any designer. Often bridges are very wide, some wider than they are long. Some of the skews are extreme and normal expansion and contraction does not occur in a direction that is parallel to the centerline of the roadway. The designer should make a careful study of the geometry of the bridge and determine how the expansion is going to take place. Specific instructions should be given on the plans as to how the bearings should be set.

Skewed bridges with intermediate expansion joints should be very carefully studied. It has been found that the skew can cause considerable longitudinal and horizontal forces on the joint and its bearings and, unless the design takes this into account, distress results. Special devices may have to be designed to carry these forces across the skewed joint.

On curved bridges, the expansion tends to be parallel to a chord drawn between the bearings rather than on a tangent to the curve. However, without instructions to the contrary, field crews could set the bearings parallel to the tangent rather than the chord. Failure of the bearing would result.

Elastomeric Pad Failures

The failures of elastomeric pads are sometimes hard to detect. Even when the pad crushes and fails, the vertical deflection may not be easy to detect. If there are voids under the pad and it pushes down, the bump in the roadway becomes more noticeable. When the pads are not completely enclosed in the structure, they should be carefully checked for cracks (especially in the bulge), for apparent aging of the material, and for any evident deterioration.

Elastomeric pads do not normally stray from proper position, whether cemented to the bearing surfaces or not. However, they can move. Therefore, if pads are visible, their position should always be checked. Also they should be in a vertical position, with due consideration for temperature deflection. In addition, they should not be pulled far over in one direction.

SIGNS OF FAILURES

Secondary failures that should alert maintenance employees to examine bearings include:

1. Cracks on the face or side of an abutment or pier originating in the vicinity of a bearing.
2. Spalled concrete (the stage following the initial cracking).
3. A bump at a bridge joint.
4. A deflection in the bridge railing at a joint. (Maintenance employees should compulsively check railing alignment.)
5. A tipped pier or abutment.
6. An expansion joint open wide, even though other joints are closed or at normal opening.
7. Streaks of rust on the face of a pier from a bearing.
8. An expansion joint jammed shut.
9. Hanger links out of plumb.
10. Rockers tipped more or less than would be expected from the current temperature condition.
11. Rockers positioned other than 90 degrees to the line of movement.

CORRECTIVE MAINTENANCE ALTERNATIVES

Corrective maintenance often entails complete bearing replacement. When something fails completely, it is often better to tear it all out and start over again using the same considerations as one would for a new job, rather than to try to patch something that has already proved to be unsuitable.

Corrective maintenance also includes rectifying any conditions that are creating difficulty (e.g., leaking expansion joints that allow water and salt to run onto bearings, or local conditions that allow wind to whip dirt and debris into bearings). These are the sorts of conditions that an alert maintenance employee can correct.

Repairs may take many forms, depending on the bearing type and on the misfortune that has befallen it. Some older bearing types, such as those with small rollers, may not be repairable and may have to be replaced. The replacement should be something more satisfactory. Some states have standard plans showing how to replace older bearings with elastomeric pads. Elastomeric pads of inferior quality may have to be replaced. Structures in areas where there have been earthquakes, slides, or other earth distortions should have their bearings checked and replaced or straightened as necessary.

Regardless of the type of bearing, when a designer is laying out a bridge, consideration should be given to how repairs or replacements to these bearings can be made. The maintenance process can be greatly simplified if the design includes space and parallel surfaces between which it is possible to slide a jack of sufficient capacity to carry the load of the adjacent bearing. If each bearing is so arranged, a set of jacks may be installed; the whole bridge lifted a slight amount; and the bearings removed, replaced, or straightened. Bearings with anchor bolts or tie-downs are more complicated. If adequate access for repairs is considered in the design stages, the need for extraordinary measures, such as cutting torches or extensive falsework to support the bridge during repair, can be eliminated.

Repair or Replace?

Discovery of a failure or partial failure can create a dilemma. Many times either repair or replacement entails a major construction job. The cause of the failure must be pinpointed before the question of whether to repair or replace can be answered. If there is a failure because of the inherent characteristics of the bearing, it would be foolish to replace it with the same thing and let it fail again. However, there are exceptions to this reasoning, such as cases in which:

1. The bearing has served its expected life span (e.g., 50 year' s service; another 50 years would probably see the structure past the end of its usefulness).
2. Replacement is easy and nothing better is available (the bridge can be jacked up easily and a replacement slipped in).
3. Only a short-term emergency repair is desired.

In general however, if a bearing failed because it could not do the job, something better should be substituted.

Complete replacement of a bearing with another type is almost always an expensive job. Often, at least a temporary bent in front of a pier or even a bent on each side of a pier from which the bridge can be jacked up is required to relieve the bearings. Some states have replaced so many bearings that they have a standard procedure for this. The frozen bearing is examined and, if the structural damage is not severe, it may be removed, cleaned, reconditioned, and then reset with the hope of a few more years of service. If there is structural damage or severe corrosion, it must be replaced, preferably with a better type. Occasionally the only alternative is a new fabrication of the failed bearing.

Some failures, when discovered, demand immediate attention. If some sort of collapse has occurred or is imminent, there is no question that it must be fixed. However, many structural failures take place very slowly—a crack slowly widens, deterioration continues slowly. Such warnings alert authorities that something must soon be done and give them time to devise the best and most permanent repair. Into which category any given failure falls is a matter of engineering judgment.

The dilemma is really an economic study: How many years has it served? How accessible is it for cleaning and repair? How long would a replacement in kind last? Is it worth removing everything to put in a maintenance-free bearing? Sometimes it is easier to string along with periodic repairs rather than mount a monumental replacement effort.

Selection of Replacement Bearings

Usually, by the time a failure occurs in a bearing, the reasons are well known. The failure could be attributed to a new product used on an experimental basis. In such a case, there may be other similar installations in which the reason for failure may be evident. If the original bearing selection is at fault (the wrong bearing for that situation), a better selection is the obvious solution. If the failure is the result of some unique situation, judgment must dictate a more satisfactory bearing replacement. No agency wants the expense of repairing bridge bearings every few years. Therefore, if a bearing has failed, an effort should be made to replace it with something that will have a longer life. Experience is a great teacher; usually after the passage of enough time for a bearing to fail, a better course of action is generally known. There should be no failures the second time.

Elastomeric pads are a reliable replacement because they are relatively maintenance-free. Some states have done very extensive replacements of various types of steel rocker and roller bearings with elastomeric pads. They have a standard replacement procedure. The replacement pads are molded as a single unit 4 to 6 in. (100 to 150 mm) thick with the elastomeric layers about 9/16 in. (14 mm) and the separator sheets of 1/8-in. (3-mm) steel. They can have TFE on one face of the pad.

COORDINATION BETWEEN MAINTENANCE AND DESIGN DEPARTMENTS

There has always been a marked lack of communication between maintenance people and designers. Maintenance personnel are notoriously self-sufficient. They take their problems as they find them and solve them to the best of their ability without asking for help from anyone. They neither brag about their clever solutions nor complain (other than among themselves) about the quality of the product that they must maintain. All of this means that unless a designer makes a determined effort to evaluate a design in the field, impractical designs will continue to be developed. There is no easy solution. Directives, orders, and reporting systems have all been tried by a number of states but the communication gap soon reasserts itself.

This is a problem that will probably never be solved. The maintenance employee lives in a different world from the designer and it is futile to hope to ever maintain active communication between them. The designer must take the initiative and seek the necessary information. When the designer asks the maintenance employee how something is working, a straightforward answer usually follows. The designer should never expect the maintenance employee to start the exchange, however.

In some states, all bridge inspection is performed by bridge engineers who then order the necessary work to be done by contract or by maintenance forces. These engineers return to the office and operate in an environment similar to that of the designers; it is possible (although far from automatic) to establish some communication between them and the designers. This way, designers can evaluate their designs. This system will work; however, it takes continual nurturing and attention. With the recent increase in major bridge repair and reconstruction by contract, bridge designers are being exposed to the conditions of existing bridge details (including bearings) and, thus, should be more aware of how their designs actually work.

Unfortunately, in the past there were designers who regarded any criticism of anything they had designed as a personal insult. Such an attitude dissuades maintenance personnel from reporting defective designs. This situation has occurred in almost every office to the point that it is extremely difficult to persuade maintenance personnel to initiate design suggestions. It requires tact, mutual understanding, and administrative firmness to maintain the communications for the good of the organization.

Maintenance personnel are glad, for the most part, to be asked for their opinions. The source of information is there for any designer who chooses to look for it. The designer must make the first step and, having done so, may find the results highly rewarding.

CHAPTER TEN

CONCLUSIONS AND RECOMMENDATIONS

• As a general policy a bridge should be designed with as few movable bearings as possible. Where allowable, the structure should be designed so that it can absorb normal movements within its elastic system, rather than having mechanical movable bearings. This can be accomplished through flexible piers, longer lengths of continuous superstructure, or limiting all expansion movement to the joints at the abutments.

• Bridge bearings are working, active mechanisms. They should be designed as such and maintained in the same way. They should be watched and cared for as one would care for the bearings in a piece of machinery.

• Bearings should be designed to require a minimum of maintenance. This applies to the basic design as well as to the inclusion of details that will make any bridge bearing easy to inspect and clean.

• Elastomeric bearings can be designed for concealed locations after the local experience record has shown them to be reliable. Until an agency is sure that elastomeric pads will perform in the agency's designs and under local conditions, they should be constructed so that they can be periodically inspected.

• Bearings do fail; whenever possible, provision should be made so that jacks can easily be inserted, the structure lifted, and the bearings either adjusted or replaced.

• Rollers and rockers are relatively trouble-free devices when properly maintained. Rollers should never be less than 4 in. (100 mm) in diameter and preferably should be larger.

• Bridges with multiple expansion joints should have restrainer bolts placed across the joints so the expansion movement will be more or less equally divided among the joints, making it impossible for all of the movement to go to one joint. Joints in earthquake-prone areas should be even more strongly restrained.

• There should be extra caution in the placement of concrete around elastomeric pads. It is not easy to place the concrete firmly against the bottom of the pad.

• Material quality is of the utmost importance in elastomeric bearings. Quality must be carefully specified. In addition, an adequate inspection and testing program should be in operation.

• Bridge bearings should be protected from dirt and water. The number of deck joints should be kept to a minimum. Where joints are used, they should be sealed or specific shielding should be provided to keep deck drainage from getting to the bridge bearings and seats.

• A regular inspection program with a complete recording system should be established by any agency responsible for maintenance of bridges. Inspection of bearings should be an important part of any regular inspection.

• The following bearing types should be avoided.
  - —Roller nests. These are impossible to maintain under normal circumstances. Dirt and corrosion inevitably cause failure.
  - —Steel radius plates with lead sheets between. These are impossible to maintain or keep clean; the lead works out and the bearing tends to freeze and lock up.
  - —Bolster shoes pinned through a girder web. The pin almost always freezes and locks the joint.
  - —Wheel-type bearings running on smaller axles. The axles always seem to freeze and lock the joint.
  - —Cast-steel bearings. Generally too expensive compared with weldments.

APPENDIX A

SELECTED BIBLIOGRAPHY

Design of Neoprene Bridge Bearing Pads. E. I. duPont de Nemours and Co. (Apr. 1959).

"Elastomeric Bearing Research." *NCHRP Report 109* (1970) 53 pp.

"Fluorogold Slide Bearings." The Fluorocarbon Co., Pine Brook, N.J. (1972).

Interim Specifications—Bridges, 1974. Amer. Assn. of State Highway and Transportation Officials (1974) 133 pp.

Interim Specifications—Bridges, 1975. Amer. Assn. of State Highway and Transportation Officials (1975) 100 p.

Interim Specifications—Bridges, 1976. Amer. Assn. of State Highway and Transportation Officials (1976) 38 pp.

"Lubrite f Expansion Bearings." Merriman, Inc. of Litton Industries, Boston, Mass.

"Lubrite Self-lubricating Expansion Plates and Bushings." *Manual 55,* Merriman, Inc. of Litton Industries, Boston, Mass.

"Manual of Bridge Design Practice." California Dept. of Transportation (1973).

"Standard Specifications." California Dept. of Transportation (Jan. 1973).

Standard Specifications for Highway Bridges. Amer. Assn. of State Highway and Transportation Officials, 11th ed. (1973) 469 pp.

"Structural Bearings by Fabreeka." Fabreeka Products Co., Boston, Mass. (1970).

Structural Engineering Handbook. McGraw-Hill (1968).

"UNI-TON Bearing System." The Fluorocarbon Co., Pine Brook, N.J.

"Wabo-Fyfe High Load Bearings." Watson-Bowman Assoc., Inc., Buffalo, N.Y.

WATSON, STEWART C., "New Design Plateaus for Bearings and Expansion Joints." Presented at a meeting of the International Bridge, Tunnel, and Turnpike Assn. (Aug. 1970).

WATSON, STEWART C., "Some 1973 Refinements in Bridge Bearing and Expansion Joint Systems." Presented at a meeting of Committee A2G03 at the 53rd Annual Meeting of the Transportation Research Board, Washington, D.C. (1974).

APPENDIX B

CALIFORNIA TESTING PROCEDURE FOR BRIDGE BEARING PADS

State of California
Department of Public Works
Division of Highways

MATERIALS AND RESEARCH DEPARTMENT

Test Method No. Calif. 663-B
April 2, 1973
(9 pages)

TESTING OF BRIDGE BEARING PADS

PART I. DETERMINATION OF COEFFICIENT OF FRICTION AND FATIGUE LIFE

Scope

The procedures to be used for the determination of the fatigue life and coefficient of friction or internal shear resistance of various bearing pad assemblies such as bronze, elastomeric, TFE (Teflon), etc., are described in this Part I.

Procedure

A. Testing Apparatus and Accessories

1. Expansion bearing pad fatigue testing machine (See photograph and schematic drawing, Figures I and II.)
2. Acetone
3. Stop watch
4. SR-4 strain indicator
5. 6-inch steel scale graduated in 1/100 of an inch.

B. Test Record Form

Use work card, Form HMR T-6028, for recording test data.

C. Specimen Preparation

1. Clean all test specimens and both platens so that they are free of any foreign substances such as dust, grit, moisture, etc., except for the lubricants used in conjunction with the bronze specimens such as oil, grease, etc. Cut the elastomeric specimens to size (standard size 6″ x 6″) and wipe clean. File smooth any rough edges on the bronze specimens and wipe clean. Use acetone to clean the bearing surfaces of TFE (Teflon) bonded specimens only.

D. Test Procedure

1. After the specimen has been centered on the lower platen of the fatigue machine, screw the eight platen leveling rollers far enough into the platen so that they do not contact the vertical guide plates.
2. Zero in the strain indicator.
3. Apply vertical load by operating valves #1 and #2.
4. Then adjust valve #6 to maintain the required pressure as read on gage #2.
5. At this time the loading platens should be parallel; check with steel scale. If loading heads are not parallel, unload and repeat the loading procedure.
6. Remove the "at rest" shims and screw the eight platen leveling rollers finger tight against the guide plates to maintain platen stability.
7. Operate the top loading platen using the following procedure:
   a. Start hydraulic pump (start button).
   b. Open valve #5 all the way and then adjust valve #4 to maintain the proper testing speed. Note: Valve #5 must be opened before speed can be adjusted by valve #4.
   c. Adjust the testing speed by the use of a stop watch.
   d. Measure the horizontal load by use of the SR-4 strain indicator.
   e. The pressure indicated on page #3 is controlled by valve #7. The function of valve #7 is to control the pressure applied to the horizontal ram.
8. At the end of the test period, stop and unload the machine by reversing the loading steps.

E. Horizontal Force Measurements

During the course of the test, record the strain gage readings to determine the horizontal force.

1. Take static coefficient of friction readings at the instant of impending motion or slip between the surfaces in question. For flexible backed TFE (Teflon) bearings, measure strain at the point of maximum displacement.
2. Obtain kinetic coefficient of friction readings by taking the average reading while surfaces are sliding. Do this in both directions of movement.

F. Calculations

$$f = \frac{F}{N}$$

Where:

F = Horizontal force due to friction or internal shear resistance (lbs).
N = Normal force (lbs).
f = Coefficient of friction
f_s = static
f_k = kinetic

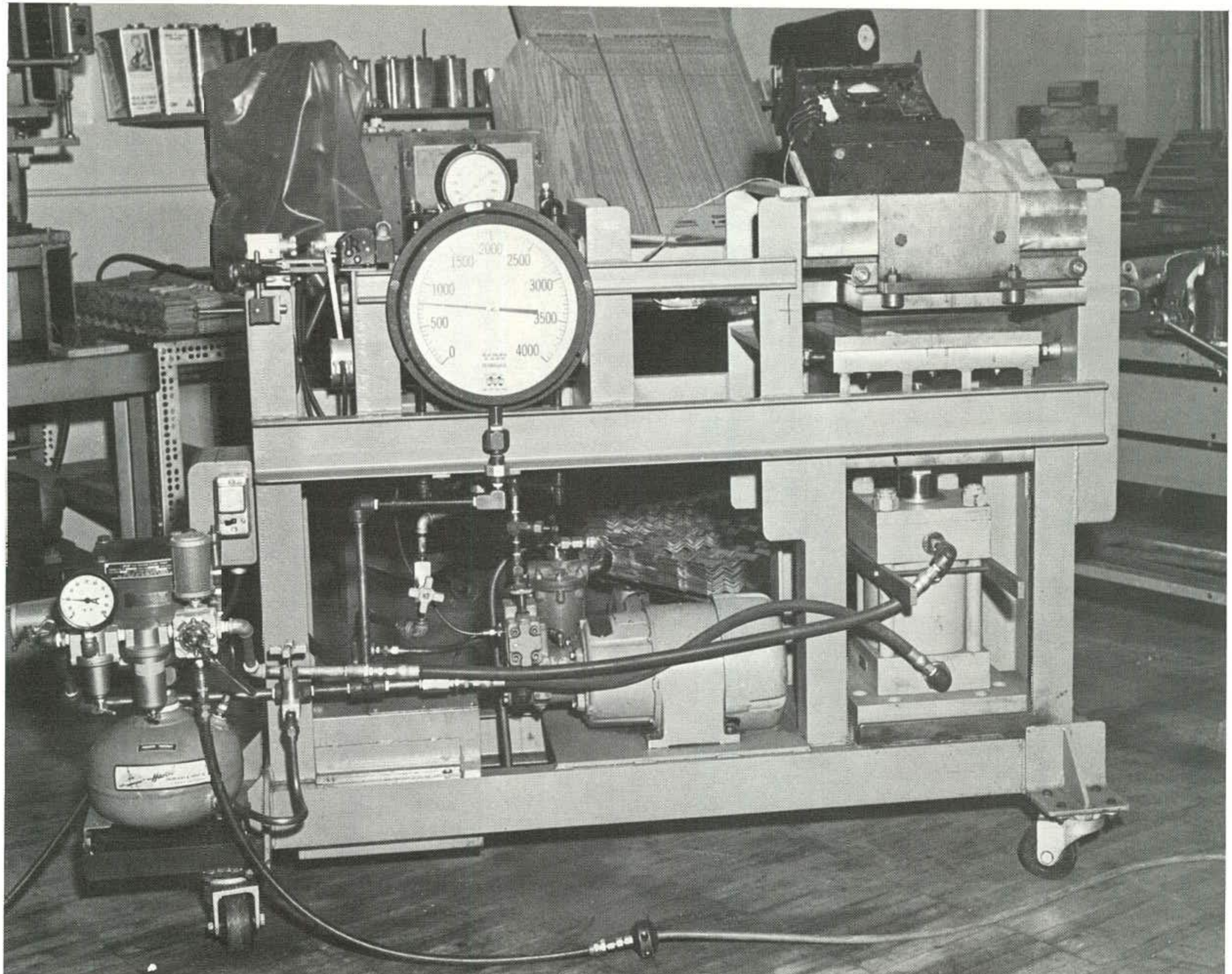
Determine "F" from the strain gage indicator readings by use of calibration plot I (Figure III). Determine N from gage #2 (Figure II) by use of calibration plot II (Figure IV).

REPORTING RESULTS

1. Report the following test results on test report Form HMR T-6028.
   a. Maximum static coefficient of friction.
   b. Average static coefficent of friction.
   c. Average kinetic coefficient of friction.
   d. Remarks concerning the specimen's appearance after completion of test, excessive wear, delamination, etc.

The "The maximum friction coefficient" as determined on Form HMR T-6028 is defined as the highest coefficient as averaged over any 50 cycles of the test.

The "Average friction coefficient" is defined as the average of at least 5 and not more than 10 readings taken between 2,000 and 8,000 cycles. These readings shall be taken at intervals of not less than 500 cycles apart.


0
500
1000
1500
2000
2500
3000
3500
4000

SCHEMATIC DIAGRAM OF FATIGUE TESTING MACHINE

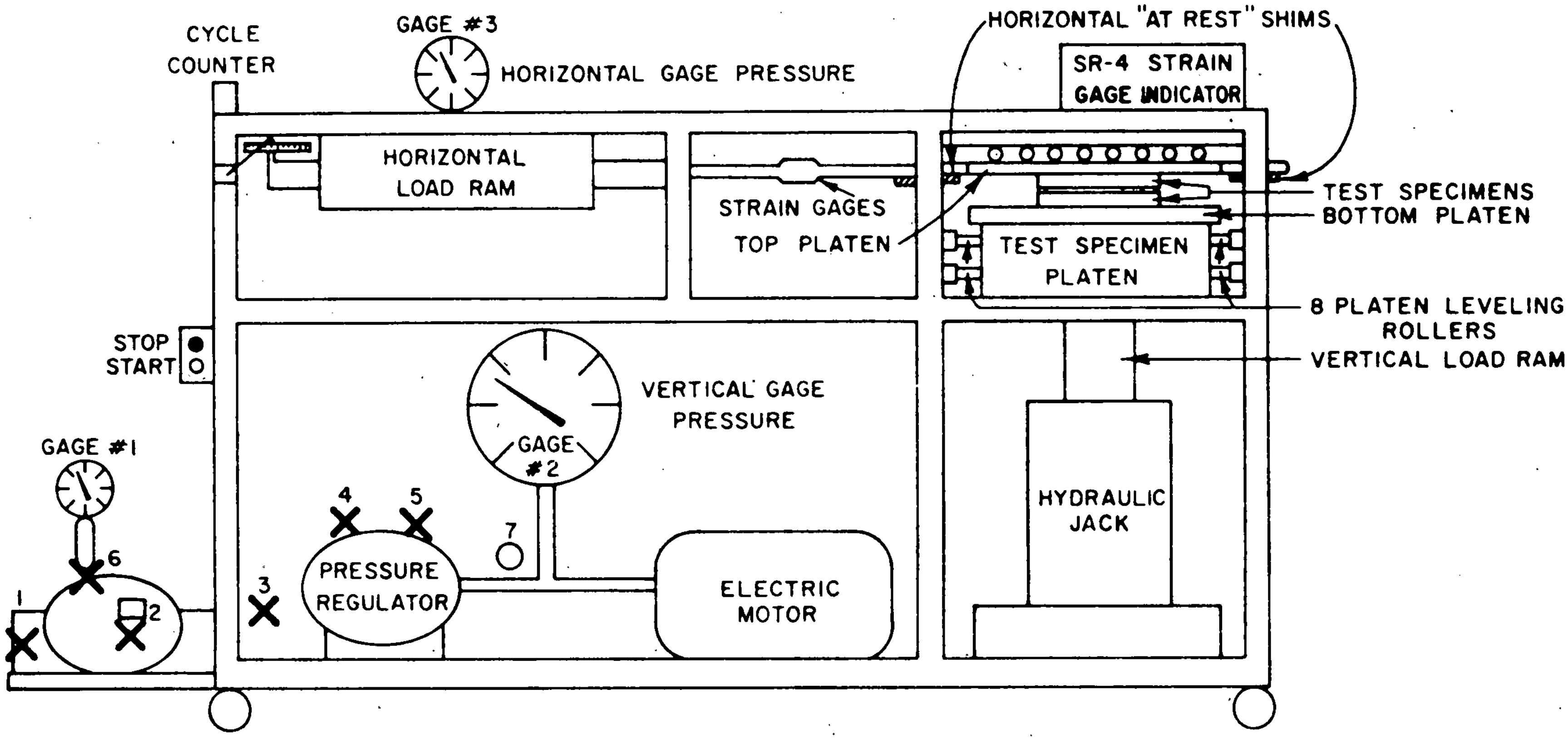


FIGURE II

BEARING PAD FATIGUE TESTING MACHINE

STRAIN GAGE CALIBRATION CURVE

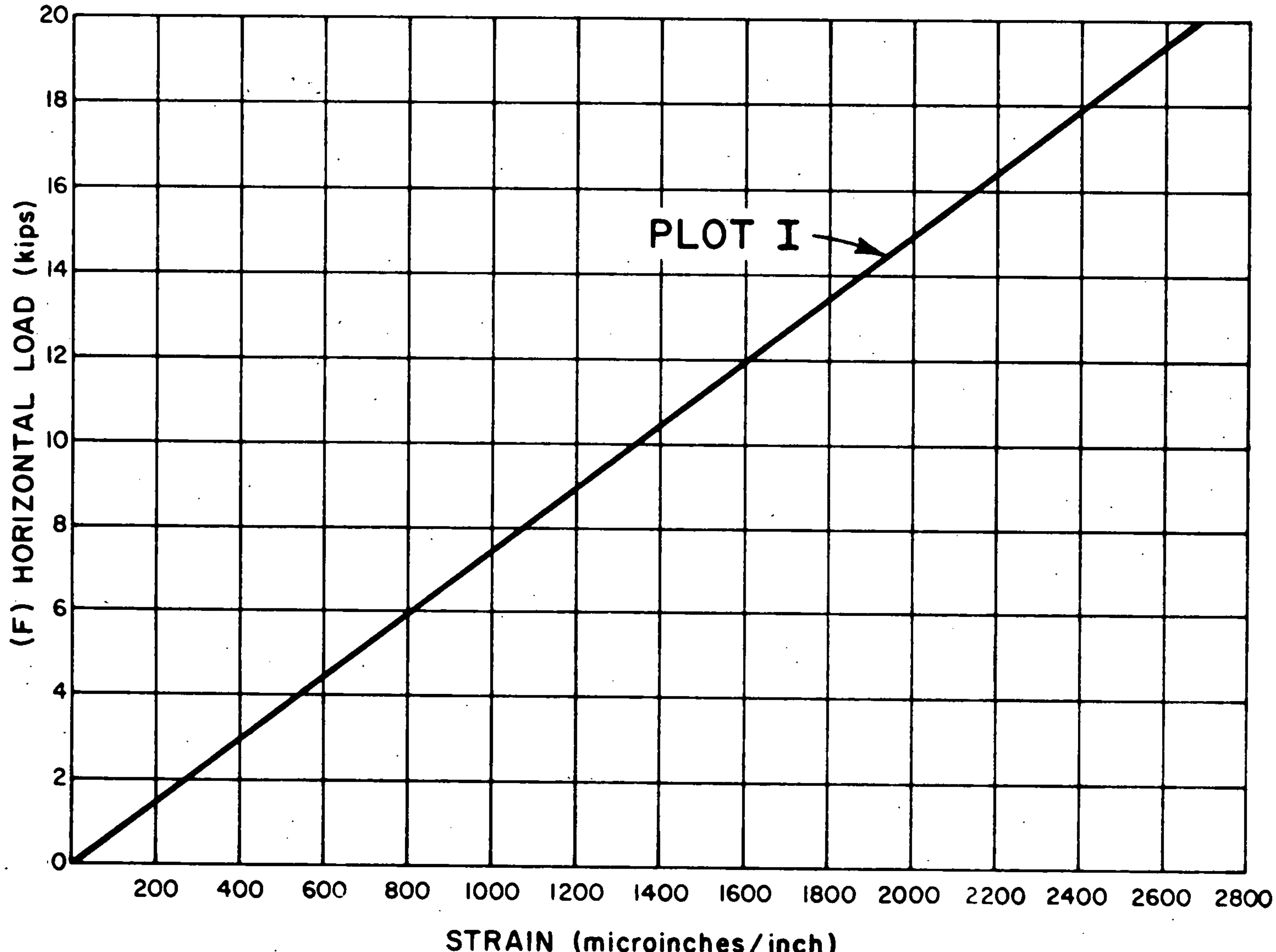


FIGURE III

BEARING PAD FATIGUE TESTING MACHINE

VERTICAL LOAD CALIBRATION CURVE

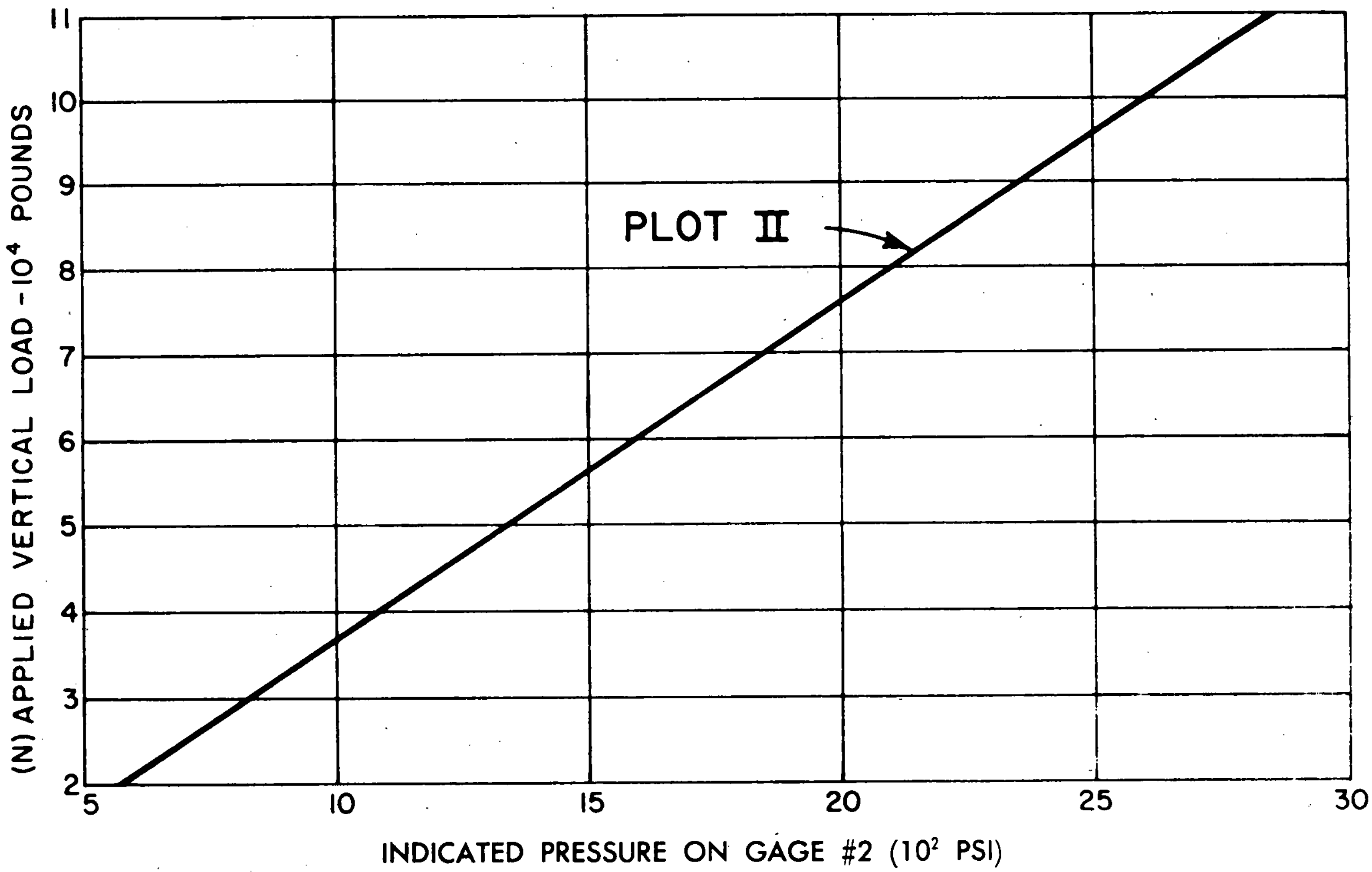


FIGURE IV

Test Method No. Calif. 663-B
April 2, 1975

MATERIALS AND RESEARCH DEPARTMENT

FATIGUE AND COEFFICIENT OF FRICTION TEST DATA SHEET

TYPE: ______________________________

SIZE: ______________________________

DATE: ______________ LOAD: ______________

STROKE: SPEED:

DRAWING OF SPECIMEN

CYCLES	SPEED INCHES/ MINUTE	+ READING	— READING	MOVING AVERAGE	GAGE PRESSURE	N KIPS	+f KIPS	−f KIPS	MOVING f KIPS	+u	−u	THICKNESS INCHES	REMARKS

HMR T-6028 (Orig. 11/66)

PART II. DETERMINATION OF PEEL STRENGTH

Scope

The procedures to be used in determining the peel strength of elastomer bonded to metal or fabric reinforcement for elastomeric bearing pads are described in this Part II.

Procedure

A. Test Apparatus and Accessories

1. A testing machine which can measure loads up to 100 pounds with an accuracy of plus or minus one percent and a platen speed of 2 ± 0.2 inches per minute.

2. Rubber grips with jaws at least one inch wide. The grips shall be capable of firmly gripping the specimen without slippage during the testing.

3. A saw capable of cutting smoothly through elastomeric bearing pads with metal or fabric reinforcement.

B. Specimen Preparation and Testing

1. Cut a one inch section (full thickness) off one side of the bearing pad sample as shown in Figure V(a). The minimum length shall be six inches.

2. Cut the section into test specimens as shown in Figure V(b).

3. Initiate peeling by neatly cutting neoprene back to neoprene-reinforcement interface. See Figure V(c).

4. Initiate uniform peeling by pulling on specimen. Separate the specimen a sufficient distance to permit clamping in the grips of the machine.

5. Install the specimen in the grips of the testing machine as shown in Figure VI. Care should be used in installing the specimen symmetrically so that the tension is applied uniformly. The grips shall concentrically maintain the specimen in a vertical direction during testing.

6. Apply the load at a uniform rate of 2 ± 0.2 inches per minute for a distance of at least two inches.

7. Determine and record the peel strength in pounds per inch. Peel strength is defined as the average load recorded on the testing machine when the specimen is slowly and uniformly peeled without snagging or binding.

Reporting of Results

Document results of tests with appropriate comments and notations on Form T-610. Report results in formal form (as complying or not complying with specifications) on Form T-6039.

PART III. DETERMINATION OF THE PHYSICAL PROPERTIES OF BRIDGE BEARING PADS

Except as shown in Part I and Part II, the other physical properties of bridge bearing pads shall be determined in accordance with the procedures as outlined in the appropriate American Society for Testing and Materials (ASTM) specifications or the American Association of State Highway Officials (AASHO) specifications, as specified in the Standard Specifications of the Division of Highways.

REFERENCE

A California Method
California Standard Specifications

End of Text on Calif. 663-B

Test Method No. Calif. 663-B
April 2, 1973

SPECIMEN PREPARATION

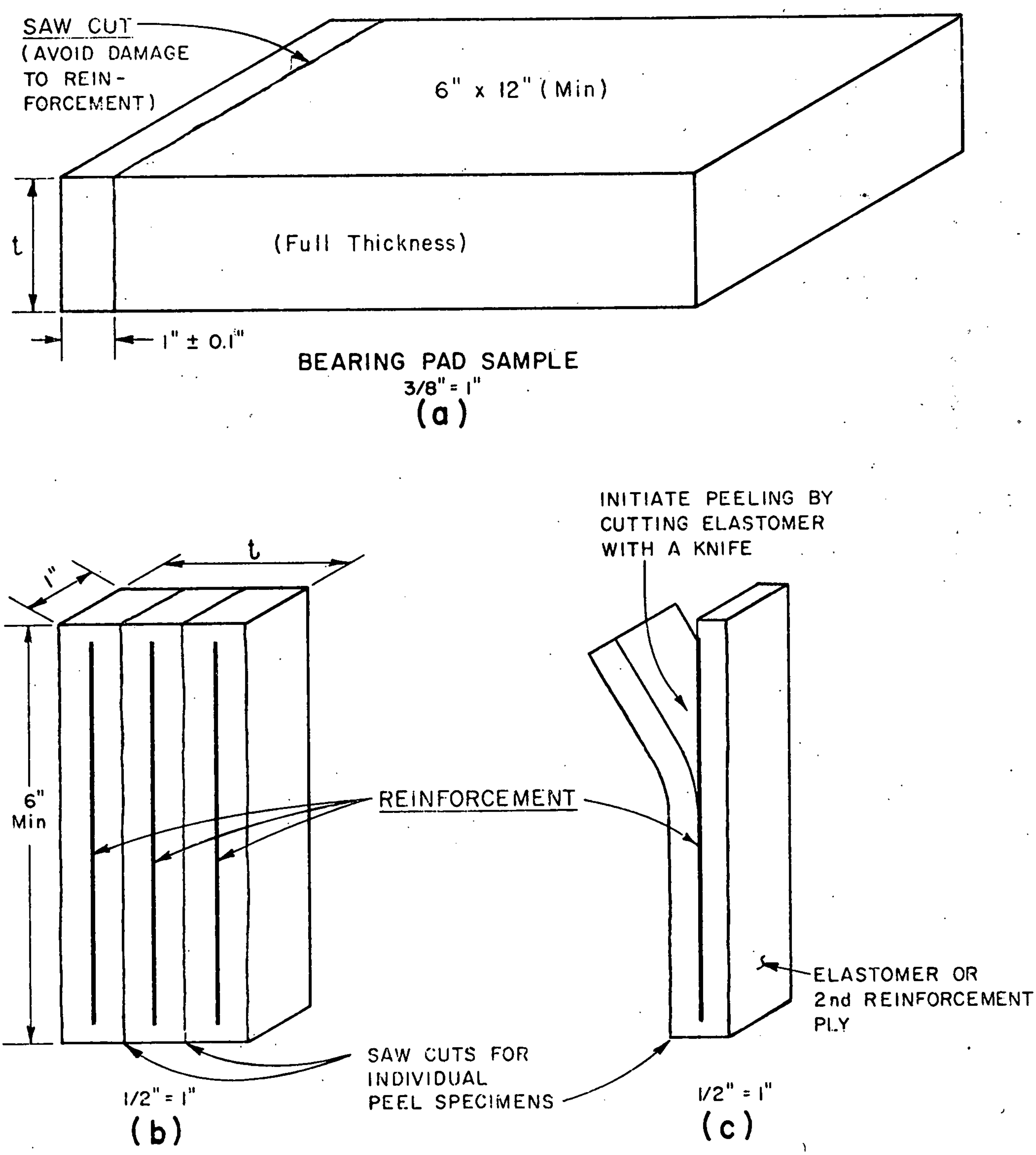


FIGURE V

PEEL TEST

Test Method No. Calif. 663-B
April 2, 1973

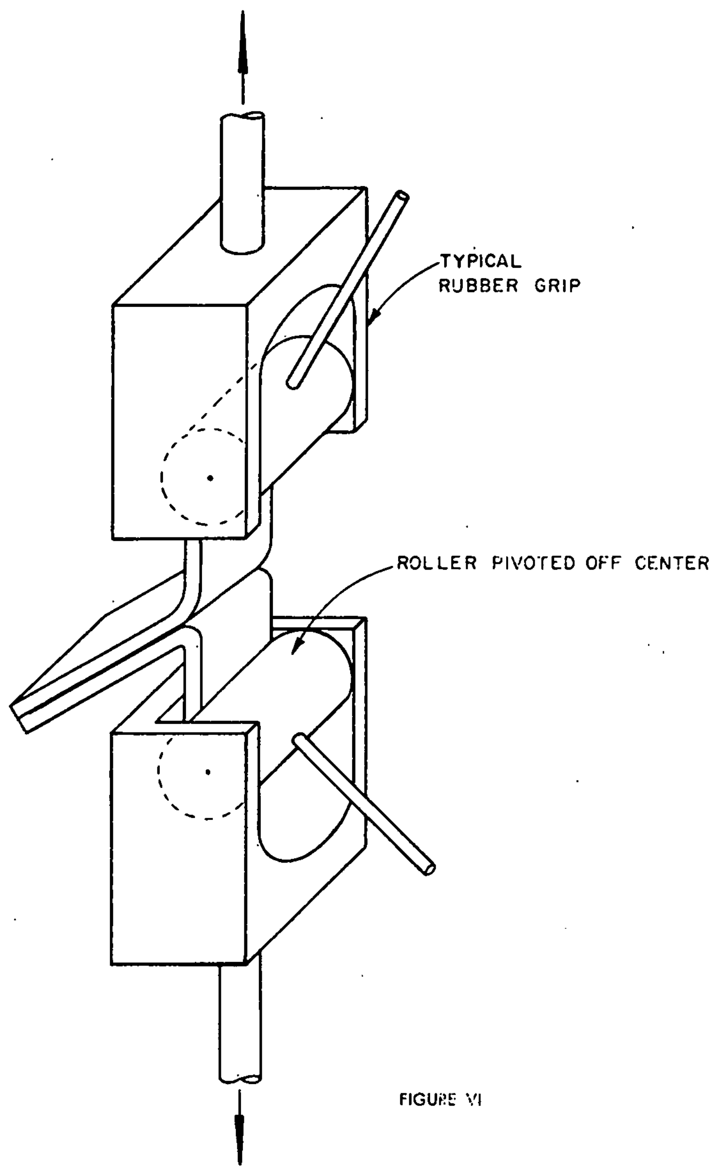


FIGURE VI

APPENDIX C

TEXAS TESTING PROCEDURE FOR ELASTOMERIC MATERIALS

Test Method Tex-601-J
(Test Method Tex-716-I)
Rev: January 1, 1971

Texas Highway Department

Materials and Tests Division

PART I

SAMPLING ELASTOMERIC MATERIALS

Scope

This test method covers the procedure for sampling elastomeric materials by authorized representatives of the Texas Highway Department. This sampling procedure covers only the sampling of the finished product at the manufacturer's plant or on the jobsite and does not include sampling procedures for pre-qualification tests. Samples for pre-qualification tests will be submitted as directed in special instructions issued by the Materials and Tests Division.

Definitions

1. Elastomeric Material. An elastomeric material is defined as a material, usually synthetic, having elastic properties akin to those of rubber. Examples: (a) Bearing pads made from compounds having virgin neoprene; (b) Waterstops made from natural or synthetic rubber or polyvinyl chloride (PVC) compounds.

2. Batch. A batch is defined as the quantity of finished material produced from each separate mixture of ingredients.

3. Lot. A lot is defined as the quantity of finished material presented for inspection at one time and may be composed of one or more batches.

4. Shipment. A shipment is defined as that quantity of finished material to be shipped to a project at one time and may include one or more lots.

5. Plain Elastomeric Bridge Bearings. Plain bearings consisting of elastomer only.

6. Laminated Elastomeric Bridge Bearings. Laminated bearings are bearings consisting of layers of elastomer interspersed with non-elastic laminates.

7. Sliding Elastomeric Bridge Bearings. Sliding bearings are those consisting of steel plate faced with TFE material and neoprene faced with TFE material; steel plate faced with stainless steel and preformed fabric faced with TFE material; or other bearings consisting of materials specifically designed for sliding action in the structure.

Sampling

1. Plain Elastomeric Bridge Bearings. A minimum of one plain bearing shall be taken for each project except when one batch or lot is used for more than one project, then one sample of that batch or lot shall represent all projects involved. Manufacturer's certificate showing the physical properties of the elastomer will be required.

2. Laminated Elastomeric Bridge Bearings. When required by the plans and/or specifications all laminated bearings will be subjected to a compressive load test, by the manufacturer, which shall be witnessed by an authorized representative of the Materials and Tests Division. All laminated bearings revealing laminate separation during or after this test shall be rejected and replaced by the manufacturer with bearings which will meet all requirements of the plans and specifications.

Should the quality of plant production become questionable, one or more samples of laminated bearings may be taken for test by the Materials and Tests laboratory.

Manufacturer's certificate showing the physical properties of the elastomer and the quality of the non-elastic laminates will be required.

3. Sliding Elastomeric Bearings. Unless otherwise required by the plans and/or specifications, one sample of a complete bearing shall be selected for each project for tests by the Materials and Tests laboratory.

Manufacturer's certificate reflecting the quality of the materials used in the manufacture of bearings will be required.

4. Elastomeric Bridge Railing Pads. Elastomeric bridge railing pads shall be accepted on the basis of manufacturer's certification and visual inspection by the Project Engineer.

5. Rubber Waterstops. Rubber waterstops shall be accepted by the Project Engineer on the basis of manufacturer's certification and visual inspection.

Failure of Samples

Any sample which fails to meet specifications shall be rejected and the batch, lot or shipment represented by that sample shall also be rejected.

Test Method Tex-601-J

June 1962

PART II

TESTING ELASTOMERIC MATERIALS

Scope

This group of tests describes procedures used to investigate elastomeric materials to determine conformity with specifications.

Procedure

Use the apparatus and specified test methods listed below to determine the properties of elastomeric materials:

Test Determination

1. Hardness (Figures 1 & 2)	A. S. T. M. Designation D 676
2. Tensile Strength & Ultimate Elongation (Figures 3 & 4)	A. S. T. M. Designation D 573
3. Compression Set (Figures 7 & 8)	A. S. T. M. Designation D 395 (Method B)
4. Low Temperature Stiffness	A. S. T. M. Designation D 797
5. Tear Test (Figures 5 & 6)	A. S. T. M. Designation D 624 -Die C
6. Ozone Cracking	A. S. T. M. Designation D 1149
7. Accelerated Extraction	Corps of Engineers CRD-C 572-60
8. Effect of Alkalies	Corps of Engineers CRD-C 572-60
9. Brittleness of Plastics by Impact	A. S. T. M. Designation D 746
10. Stiffness in Flexure	A. S. T. M. Designation D 747

11. Test on Rubber After Oven Aging

Hardness	A. S. T. M. Designation D 676
Tensile Strength & Ultimate Elongation	A. S. T. M. Designation D 412

12. Adhesion Test

This is a special test or group of tests used to determine the degree of adhesion present in the bond between the elastomer and any type of reinforcing material such as metal, fabric or other material contained in a specified assembly. When a force applied at a rate, direction, magnitude, frequency etc. necessary to cause separation within the assembly is brought to bear upon the assembly then any separation which occurs between the various component parts of the assembly shall occur within the elastomer itself rather than at the interface between the elastomer and the reinforcing material. Separation at the bond or interface shall be arbitrarily defined as an "unsatisfactory separation" and shall constitute failure to pass the described "Adhesion Test." All tests are conducted at a temperature between 70 and 90 degrees Fahrenheit and the methods used to induce separation will vary with the type of reinforcement and with the physical dimensions and type of the specified assembly. The purpose of this test is to insure that an adequate bond has been obtained between the various components of the assembly. The means and methods used to determine the adequacy of this bond will vary depending upon the particular assembly involved but in each case the governing criteria will apply: "All bond failures shall occur within the elastomer itself, rather than at an interface."

Test Record Forms

Record test data on Form D9-2J and report test results on Form 231.

Figure 1

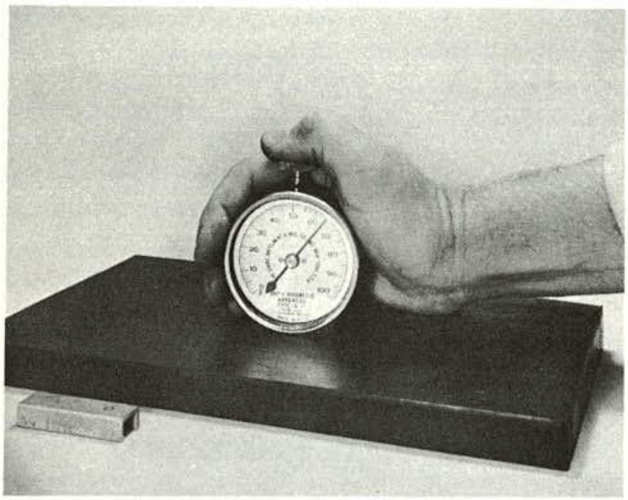


Figure 2

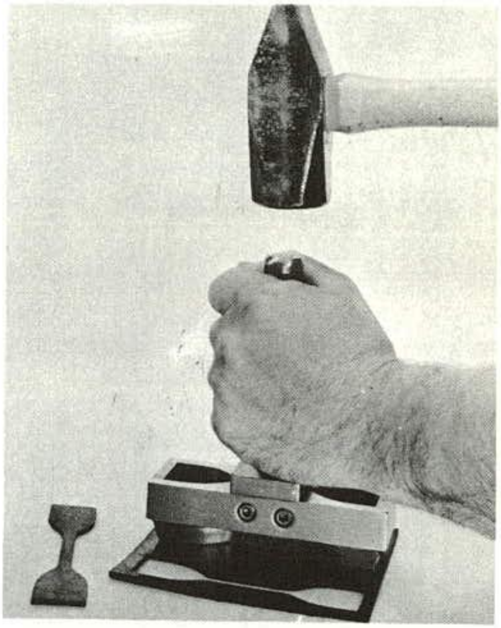


Figure 4

Figure 3

Figure 5

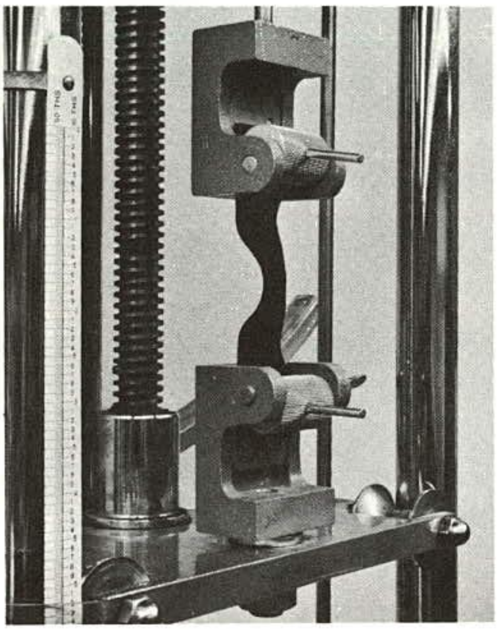


Figure 6

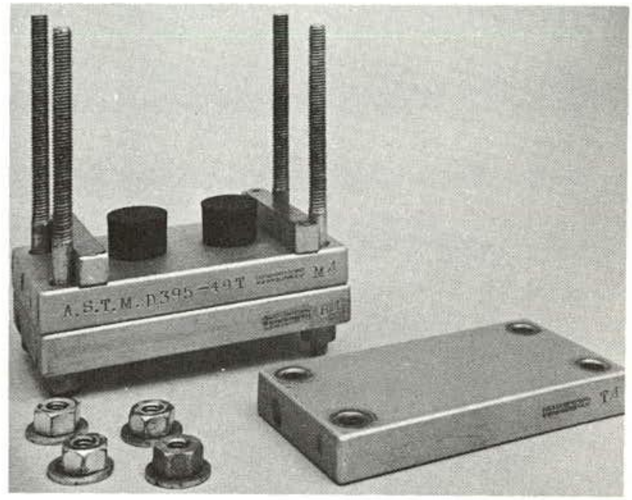


Figure 7

DATE	NEOPRENE RUBBER TEST	LAB. NO.
SAMPLE DIMENSIONS	SAMPLE IDENTIFICATION	PRODUCER
CHANGE IN DUROMETER HARDNESS	SPECIFICATIONS DUROMETER: COMPRESSION:	STENCIL NO.
NEOPRENE YES ☐ NO ☐		

DUROMETER										AVERAGE
INITIAL										
FINAL										

NO.	T_o	T_s	T_1	$T_o - T_1$	$T_o - T_s$	$\frac{T_o - T_1}{T_o - T_s}(100)$	AVERAGE AND INITIALS

FORM D9-2-J

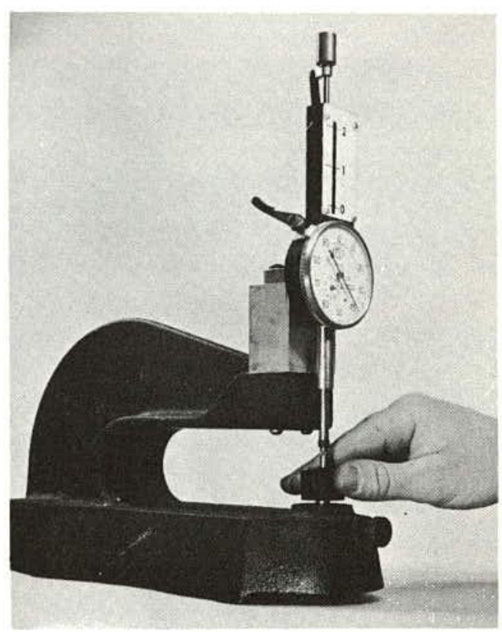


Figure 8

THE TRANSPORTATION RESEARCH BOARD is an agency of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. The Board's purpose is to stimulate research concerning the nature and performance of transportation systems, to disseminate information that the research produces, and to encourage the application of appropriate research findings. The Board's program is carried out by more than 150 committees and task forces composed of more than 1,800 administrators, engineers, social scientists, and educators who serve without compensation. The program is supported by state transportation and highway departments, the U.S. Department of Transportation, and other organizations interested in the development of transportation.

The Transportation Research Board operates within the Commission on Sociotechnical Systems of the National Research Council. The Council was organized in 1916 at the request of President Woodrow Wilson as an agency of the National Academy of Sciences to enable the broad community of scientists and engineers to associate their efforts with those of the Academy membership. Members of the Council are appointed by the president of the Academy and are drawn from academic, industrial, and governmental organizations throughout the United States.

The National Academy of Sciences was established by a congressional act of incorporation signed by President Abraham Lincoln on March 3, 1863, to further science and its use for the general welfare by bringing together the most qualified individuals to deal with scientific and technological problems of broad significance. It is a private, honorary organization of more than 1,000 scientists elected on the basis of outstanding contributions to knowledge and is supported by private and public funds. Under the terms of its congressional charter, the Academy is called upon to act as an official—yet independent—advisor to the federal government in any matter of science and technology, although it is not a government agency and its activities are not limited to those on behalf of the government.

To share in the tasks of furthering science and engineering and of advising the federal government, the National Academy of Engineering was established on December 5, 1964, under the authority of the act of incorporation of the National Academy of Sciences. Its advisory activities are closely coordinated with those of the National Academy of Sciences, but it is independent and autonomous in its organization and election of members.

TRANSPORTATION RESEARCH BOARD

National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

ADDRESS CORRECTION REQUESTED

NON-PROFIT ORG.
U.S. POSTAGE
PAID
WASHINGTON, D.C.
PERMIT NO. 42970

000015M003
MATERIALS ENGR

IDAHO TRANS DEPT DIV OF HWYS
P O BOX 7129
BOISE ID 83707