

Importance of Proper Anchoring

By EDWARD COHEN

Reliability, economy, and simplicity should be the criteria for selecting an anchorage or connection detail. Each anchorage must be of adequate strength to perform its assigned task, must be the proper type for the application, and must be able to provide satisfactory service throughout the life of the structure.

Experience has shown that the critical points of structures are the connections. As a result of the increased use of higher strength materials and the higher stresses with which we now work, more stress per square inch or cubic inch must be transferred between structural elements than ever before. It is at these points that stresses are concentrated and the greatest care in design, detailing and construction is required. Because connections often control the ductility and strength of the over-all structures, it is here that designers and constructors should exercise extra caution in evaluating the loadings caused by volumetric effects, and lateral and vertical forces, in establishing the required strength and in providing adequate ductility.

Examples are presented to point up the difficulties, accomplishments and goals for proper anchoring of and to concrete.

Keywords: anchorage; anchors; bridge anchorages; bridges (structures); buildings; concretes; connections; construction; ductility; fasteners; loads (forces); precast concrete; quality control; reinforced concrete; strength.

■ WHETHER AN ANCHORAGE REQUIRES 207,000 cubic yards of concrete, as for the cables of the Verrazano-Narrows Bridge or a small diameter anchor bolt, reliability, economy, and simplicity are of prime importance. Every anchorage must be of adequate strength to perform its assigned task, must be the proper type for the application, must be capable of required quality installation under field conditions, and must be able to provide satisfactory service throughout the life of the structure.

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Joints and connections require great care in design detail and construction. Joints and connections are regions in which the increasingly higher stresses used with modern higher strength materials are transferred. However, they are often the most difficult portions of the structure to construct because of the congestion of reinforcement and difficulty of placing concrete or because of difficulty of controlling field operations. Yet it is at these points that the designer bears his most difficult burden for, if the full capacity of the member can not be developed at the connection, part of the available structural strength is wasted.

Based on experience and extensive laboratory tests of structural members factors of safety have been reduced. Because of the need to avoid catastrophic errors and the lack of complete control over many of the factors this reduction has been a slow and careful process. Still, within the main lengths of members reductions in factors of safety have been initiated and further reductions are contemplated. The question which must be answered affirmatively is whether the same degree of knowledge and security is applicable to connection design and construction.

JOB OF THE CONNECTION

The ability of reinforced concrete to sustain unanticipated loads and distortions by redistribution of stress has been one of the important factors in maintaining its excellent safety and serviceability record. Many variations of creep, shrinkage, settlement, loading, and strength

from those assumed in the calculations have occurred without trouble under the umbrella of ductility.

In addition, for structures resisting dynamic loads or distortions such as earthquake or blast, ductility is of equal or greater importance than initial strength. In the case of earthquakes the calculated stresses are often fictitious values based on empirical methods derived from previous experience or on past earthquake records at other sites. In each case there is no reliable guide to the magnitude of future earthquakes or the degree of damage or the degree of catastrophe that can be anticipated under future conditions unless large plastic distortions can be experienced without failure. In the case of blast loading, the plastic energy absorption after yield may be hundreds of times that in the elastic range. Connections and anchorages which can develop the ultimate strength of structures are desirable in all cases and particularly where dynamic loadings are to be resisted or where settlement, volumetric efforts, etc., may require substantial ductility.

Where a mechanical connection is provided between two simple spans, this connection must be able to carry not only the stress indicated by elastic analysis for the superimposed live loads but also the higher stresses which may be induced by creep, shrinkage, temperature, or other volumetric effects. The alternative is to assure sufficient ductility in the connection to permit self relieving strains to control the stress within the capacity of the section.

Although the concept of high ductility may be more important than high strength, the two cannot be separated. If we consider the ideal stress-strain curve we learned about at school, with a sharp yield point and a long flat region of strain at constant stress, the yield stress criteria for design of a bar to bar tensile connection would appear adequate. However, the possible stress-strain curves of the high strength steels which are now in use exhibit gradual yield and a continuously rising stress-strain relationship. It appears, therefore, that in such cases the maximum ductility may be achieved only if the connection can develop the full strength of the bar.

In the burgeoning market of concrete construction the economic pressure to reduce the total costs has yielded many outstanding developments. In the drive to reduce the number of man-hours per cubic yard of concrete and the amount of concrete per square foot of building area concrete of 5000 psi is now in common use, and 6000 to 7000 psi concrete does not raise eyebrows. Strengths of reinforcing bars have more than matched these developments in concrete. From 33,000 psi, steel strengths have risen to 40, 50, 60, 75, and occasionally 90,000 psi. Because of the development of techniques and an increased awareness of its potential, precast and prestressed concrete have, in the past 25 years, taken an increasing share of the total concrete construction mar-

ket. These developments have brought new problems and higher stresses to the critical connection points. To handle these problems, designers, manufacturers and constructors together, have developed new procedures, and adapted some old techniques to get the most out of their members.

ECONOMY AND SIMPLICITY

While the cost differential between providing adequate and inadequate anchorage usually has only a nominal effect on the over-all construction cost, any difference in connection cost becomes a major advantage or disadvantage between bidders. As a result the fabricator and erector are put under considerable pressure to minimize as much as permitted by the engineer. Too often the plans and specifications have left the selection and detailing of connections open, without providing a yardstick to measure the final result and without briefing the bidders as to the design concept and connection requirements for strength, ductility, and dimensional tolerance.

While designers constantly strive to make the connections as simple as possible, other than structural considerations often make simplicity a relative thing. Simplicity of design must begin with an understanding of the task that the connection is meant to perform. Whether large or small, steel or stone, each anchorage must be adequate to its assigned task. It is the definition of the task which is sometimes difficult. Yet, the simplicity of the connection is dependent on the clear understanding of the task.

RELIABILITY

In addition to economy and simplicity one of the important attributes of satisfactory anchorage is reliability. An important aspect of reliability is permanence. To initial adequacy must be added assurance against corrosion, fatigue, and other time dependent effects. Reliability can be achieved in different ways, but the path becomes longer and the pitfalls more numerous as the magnitude of the "fastener" leaps from a suspension bridge anchorage, to a slab insert designed to anchor a rod supporting a light piece of mechanical equipment.

In the case of the suspension bridge anchorage, the concept, the materials, the distortions, the loadings are all thoroughly investigated and engineered to establish a well-defined capacity. Full allowance is made for all possible variations in analysis, material properties, loadings, and construction and time dependent effects.

In the case of mass produced elements, the requirements of uniformity or quality control must be added to the above. This requirement for quality control does not end with the packaging of the components at the

manufacturing plant. It extends to the actual installation and the workmanship in the field. If the quality or uniformity of field workmanship is reduced, variations in the installed capacities of fasteners increase, and requirements for field testing and inspection increase. The spiraling effect on construction cost and time may make a theoretically sound fastening system impractical if great skill is required for installation.

In some cases difficulties result not from poor workmanship but from lack of proper coordination between trades. For example, lack of mutual understanding of the limits of permissible misalignment of two components to be connected can turn a relatively simple and reliable detail into a nightmare of complexity and doubt. The willing and knowledgeable cooperation of the constructor is the most important single factor in building a structure that reflects the intent of the plans and specifications. Such mutual understanding is far more effective than rigid inspection during construction, although inspection plays an important part in the construction picture. The designer must not dictate to the fabricator from an ivory tower or from a design office insulated from the practical problems of construction. The designer, with a full knowledge of relative costs and availability and in cooperation with constructors must arrive at an acceptable solution to the connection problem. To gain the cooperation of the builders, pre-bid conferences to explain new details or procedures can be rewarding to both the bidders and the owners.

EXAMPLES

Some examples of anchorage solutions will illustrate the range of problems which may be encountered.

In the case of the Verrazano-Narrows Bridge across the entrance to New York harbor, the anchorage is one of the most critical features. The anchorage was required to develop a maximum tension of 250,000,000 lb exerted through four 36 in. diameter high strength steel cables. In this case mechanical "fasteners" were provided to anchor the cables to over 207,000 cu yd of concrete, which resists the pull by dead weight and friction. This is obviously not an ideal spot for lightweight concrete.

The eyebar chains consist of three tiers of 244 bars each, for a total length of 100 ft. The upper head of the middle tier and the lower head of the upper tier bars have elongated holes to allow for shimming needed in cable adjustments. The general details of the anchorage are shown in Fig. 1-1. Fig. 1-2 shows the supporting frame and eyebar chains under construction.

The supporting frames are of ASTM A 7 steel. Adjustment is provided between sections of the frame erection to permit compensation of settlement motions. The pins connecting the eyebars to each other

and to the anchor girders and strand shoes are forged steel conforming to ASTM A 237. Shims and wedges are provided at all eyebar support points to permit the bars to be set as accurately as possible. Live load tension plus dead load produces a small eccentricity in the eyebars but a far larger eccentricity is caused by unavoidable fabrication and erection inaccuracies and by anchorage settlements.

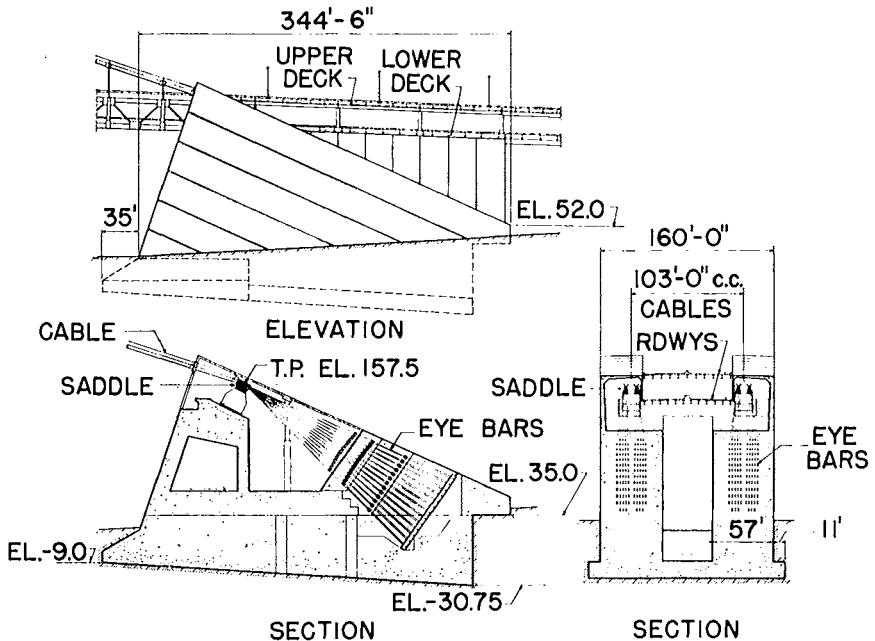


Fig. 1-1—General details Brooklyn anchorage Verrazano Narrows Bridge, Brooklyn, N.Y.

The eyebars are cut from plates conforming to ASTM A 441 which is a weldable grade of steel. The ASTM specification was modified by the addition of requirements for 0.15 percent minimum silicon and the manufacture of the plates by fine grain practice. The fine grained killed steel was considered to be tougher than the basic A 441 steel.

As a further protection, all bars were stress relieved after flame cutting and were carefully examined for edge cracking at the flame cut edges. An extra 1/8 in. width of metal at each edge was used in the shank to permit grinding of edge cracks. The locations of the tensile coupons and bend test specimens were specified to guard against the systematic production of weak or brittle bars. Past practice with quenched and tempered steels required that 3 to 5 percent of the full size bars be tested to destruction. This considerable cost was reduced

by the elimination of heat treatment and by the use of a standard steel. However, a few full size tests in advance of production fabrication were made to check the adequacy of the design of the heads.

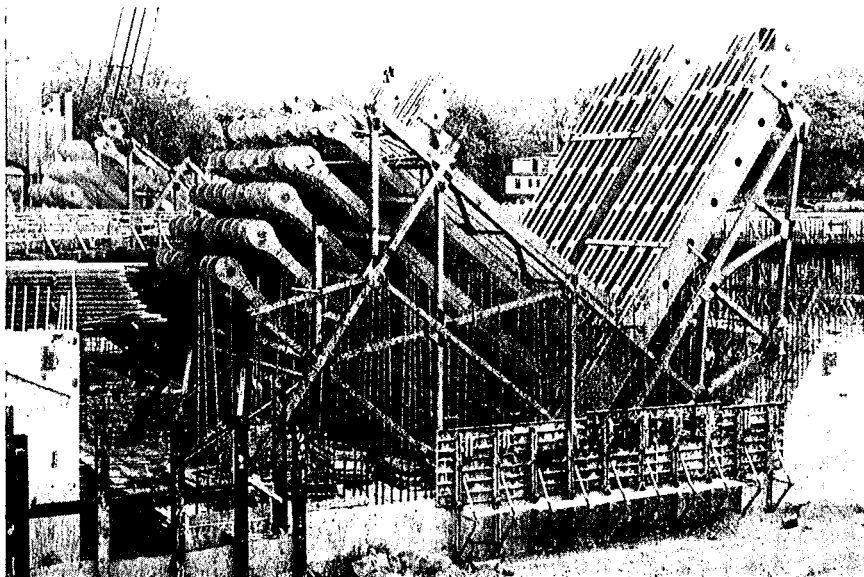


Fig. 1-2—Supporting frame and eyebar chains, Verrazano Narrows Bridge, Brooklyn, N.Y.

A recent circular structure is the Oakland Coliseum in Oakland, Calif. The clear span roof is a cable supported precast concrete system which relies on mechanical fasteners for full strength reinforcing bar splices in both tension and compression. The roof framing consists of 96 radial stiffening ribs, one of which is shown being erected in Fig. 1-3, each supported on a $2\frac{3}{16}$ in. round bridge strand which spans between an exterior cast-in-place ring girder and an inner 45 ft diameter steel tension ring. The end of one rib section is shown in Fig. 1-4.

The constructor was able to erect the radial ribs in two sections each approximately 90 ft long. The depth of each rib varied over its length between 22 ft and 8 ft. All splices were made in the air after all dead load was in place so as to minimize initial stresses in the ribs and the circumferential diaphragms.

Although the precast members were made on the site a close dimensional control was maintained. The connector sleeves were made extra long to provide against some contingencies in length of these large members. The bars were A 432 and the main steel varied in size from #9 to #11.

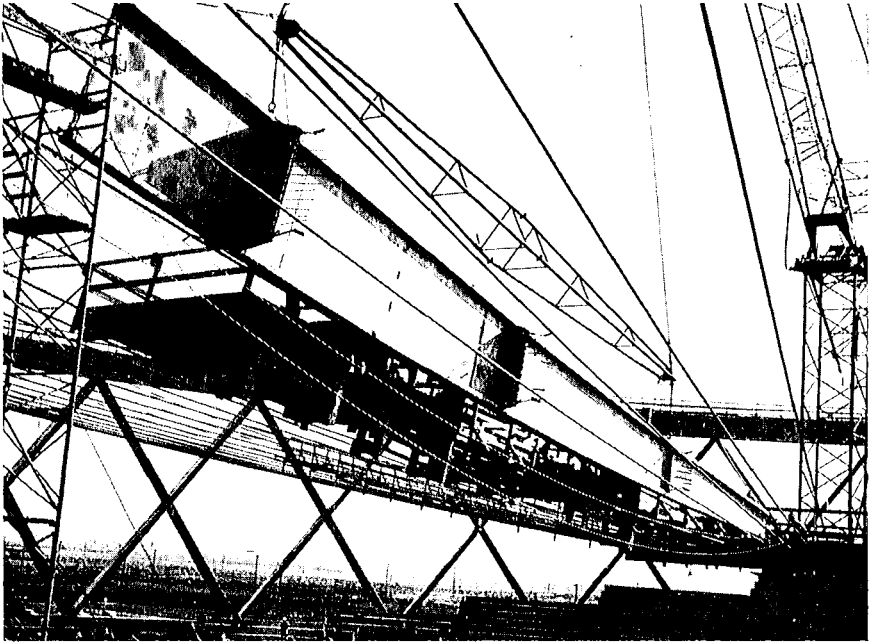


Fig. 1-3—Radial stiffening roof framing rib, Oakland Coliseum, Oakland, Calif.

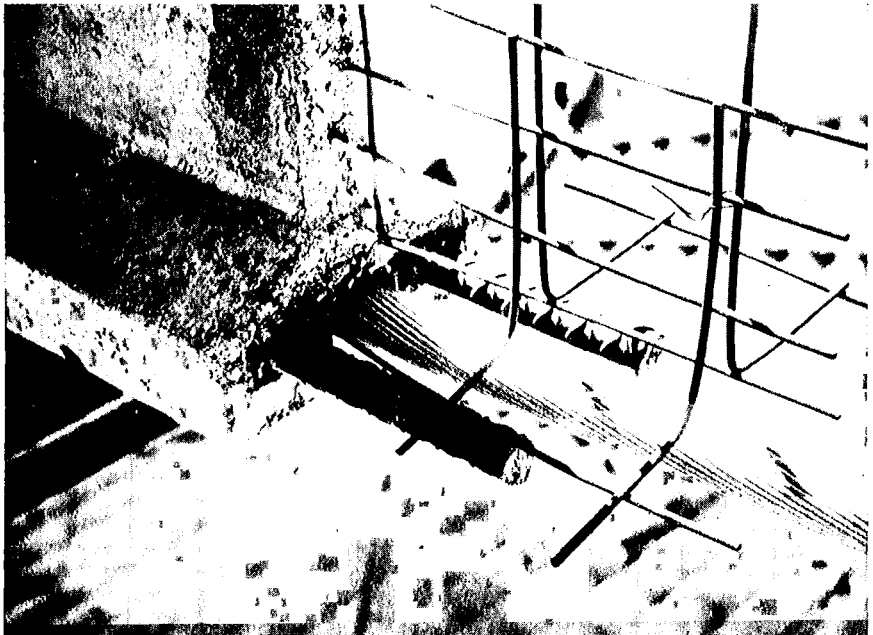


Fig. 1-4—Radial rib end, Oakland Coliseum, Oakland, Calif.

The Science Museum at the New York World's Fair, now a permanent feature of the New York City Department of Parks, is a structure completely enclosed by a free-standing, serpentine, cellular, ribbed wall approximately 100 ft high. This wall originates at the terrace level and is supported at this level by a radial beam and ring girder system, which, in turn, is supported by columns. The deep beams and girders were heavily reinforced with #11 bars and larger. When it came to joining the keystone shaped ribs of the walls to these beams and girders, there was just not enough room for the #8 and #9 vertical bars of the ribs to fit between the heavy reinforcement of the beams and girders.

The solution involved the first full tension splice utilizing Cadweld sleeves ever used in New York City, and, thus, an innovation into the city building code. A steel plate was attached under the vertical ribs to the beams or girders by means of vertical bars of sufficient number to develop the tension at the connection. These bars were inbedded in the girders within the periphery of the plate and the plate was then welded to the bars. A template of the rib was then laid on the plate to locate the position of the connection sleeves which were subsequently fillet welded to the plate to take the rib's reinforcing bars (Fig. 1-5). The rebars of the ribs were then Cadwelded to the plate. This unique solution to a difficult problem demonstrates the application of a fastener system beyond the original intention of the manufacturer.

For the Metropolitan Opera House at New York's Lincoln Center precast concrete columns were placed 3 ft on center around three sides of the building. The precast units were 10 x 19 in. and 10 x 27 in. The larger units were 60 ft in height. The public area of the building was framed in concrete whereas the stage area was steel framing. Connections had to be devised between the precast columns and the steel and concrete

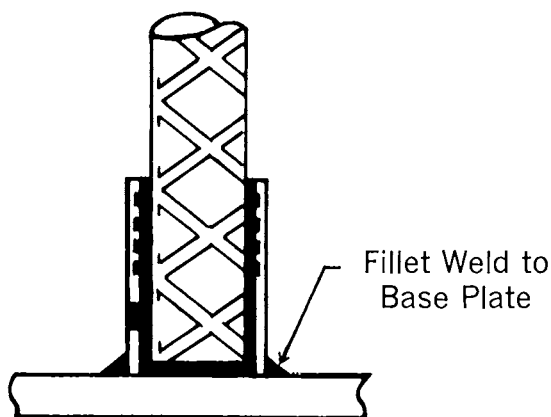


Fig. 1-5—Reinforcing bars in connection sleeves, New York Science Museum

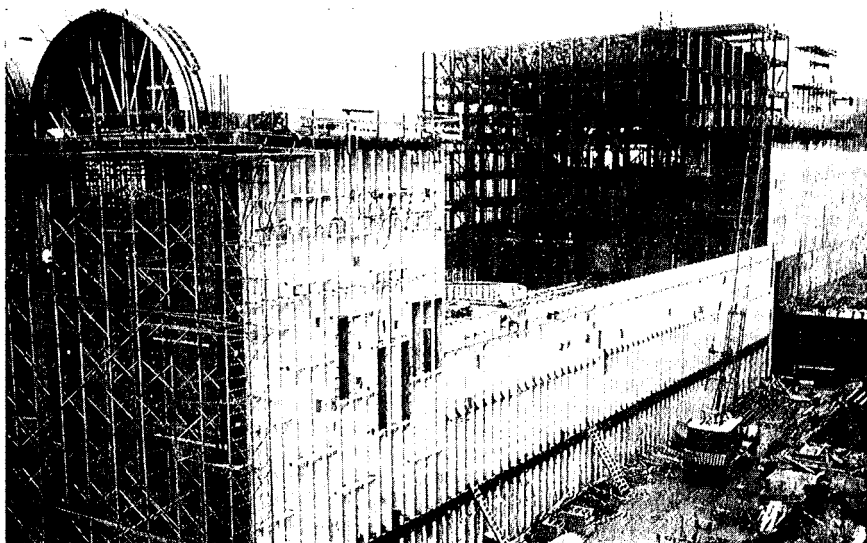


Fig. 1-6—Precast concrete columns and steel framing, Metropolitan Opera House, New York

framework. Fig. 1-6 shows the two distinct sections of the Opera House and some of the precast members in place.

In connecting the precast units to form the perimeter columns, care had to be taken to produce a neat joint without chipping the rounded corners from the precast units. From a recess in the top of the lower precast unit, two $1\frac{1}{4}$ in. steel dowels protruded. A neoprene gasket was fitted around this recess. Sleeves to receive the steel dowels made from $\frac{1}{4}$ in. plates welded to a $4 \times \frac{1}{4}$ in. plate with $1\frac{3}{4}$ in. holes were in the bottom of the next precast unit. One $\frac{3}{8}$ in. grout injection pipe led into the sleeves from outside the column unit. (Fig. 1-7). The columns were erected in series of some 60 columns at one time. When the next level of precast units were in place for the series of columns the alignment was adjusted. Once they were all aligned the grouting in place was a simple and swift operation.

The concrete beams were connected to the precast concrete units as shown in Fig. 1-8. The $1\frac{3}{4}$ in. recess in the precast unit, against which the beam was cast, was sufficient to keep the beam from sliding. Through sleeve nuts above and below the recess, anchor bolts in the precast unit were connected to $1\frac{1}{8}$ in. anchor bolts, two at the bottom and two at the top, in the floor beam. Because of the restricted clearance which was available in the top of the beam the anchor bolt lengths were detailed individually to avoid placing problems.

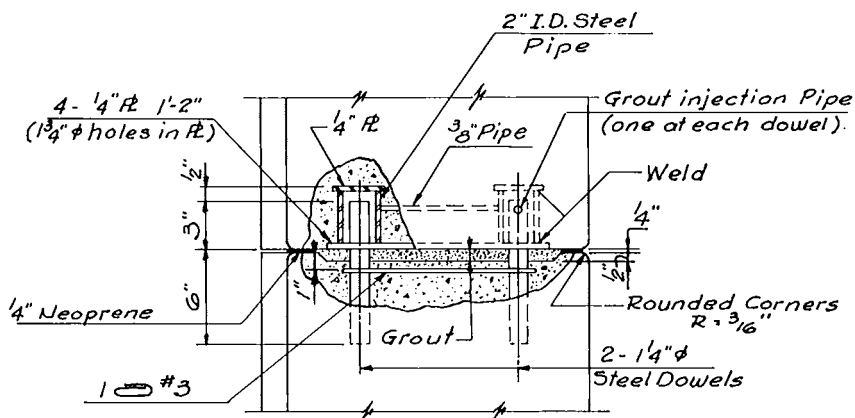


Fig. 1-7—Connections for precast units, Metropolitan Opera House, New York

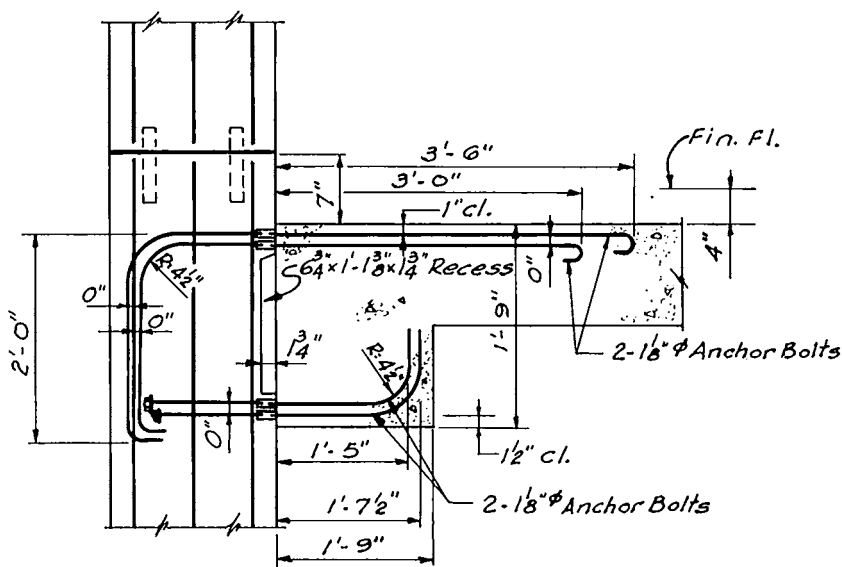


Fig. 1-8—Connection of concrete beams to precast units, Metropolitan Opera House, New York

An economical and efficient connection to the 21WF beam was made through the use of $1\frac{1}{4} \times \frac{5}{8}$ in. steel bands (Fig. 1-9). The bands, arched in the precast units so that the forces acted normal to their entire surface, were welded to a $\frac{5}{8}$ in. plate on the surface of the precast unit. Four $\frac{7}{8}$ in. anchor bolts connected the plate to another $\frac{5}{8}$ in. plate. Welded plates connected the web of the 21WF beam to the $\frac{5}{8}$ in. plate.

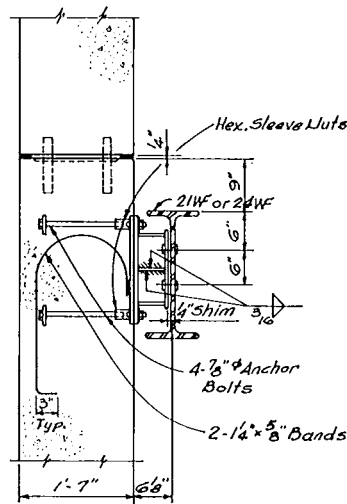


Fig. 1-9—Connection of steel beams to precast units, Metropolitan Opera House, New York

CONCLUSIONS

Common features of all anchorage solutions should be reliability, economy, simplicity and suitability. Connections are the most critical points of concrete structures. As a result of the increased use of higher strength materials and the higher stresses with which we now work, more stress per square inch or cubic inch must be transferred between structural elements than ever before. It is at these points that stresses are concentrated and the greatest care in design, detailing and construction is required.

The illustrations presented in this paper have shown connections designed with a concern for what can be built. Based on a full knowledge of relative costs and availability, and in cooperation with constructors, the designer must arrive at an acceptable solution to the connection problem. Because a relatively simple and reliable detail can be turned into a nightmare of complexity by misapplication or lack of coordination between trades, the understanding and cooperation of the constructor is a vital ingredient in the successful execution of a connection or anchorage system.

The Anchorage of Residential and Other Light-Frame Buildings to Concrete in Storm-Resistant Construction

By E. GEORGE STERN

Experiences based on storm damage during the past few years indicate that buildings can be erected without major increase in cost to withstand the ravages of storms, provided resistance to forces encountered during storms has been given careful consideration by the designer. This is especially the case in light-frame construction, where large overhangs can result in high uplift forces and even overturning of the building, if all the components from roof down to the foundation are not anchored satisfactorily to the ground.

The builder, who takes advantage of existing knowhow in anchoring his building satisfactorily all the way down to the ground, will not only profit from such desirable practices, but assist in the economic development of those areas which have been subject to high storm damage.

Using a typical residential building as an example, design considerations and construction details are advanced which can help make a building storm-resistant in areas with either moderate or severe storm exposure.

Keywords: anchorage; anchors; bolts; building codes; buildings; commercial buildings; concretes; fasteners; foundations; framed structures; loads (forces); nails; panels; powder actuated tools; precast concrete; reinforced concrete; residential buildings; safety factor; stability; storms; studs; walls; wind loads.

■ ANCHORAGE OF RESIDENTIAL, INDUSTRIAL, and agricultural buildings to their foundations has become a matter of major concern only during this

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generation. Numerous structures had been erected satisfactorily without any anchorage. These older buildings, however, are usually large, of heavy construction, and of more than single-story height. Their own weight prevented them from being moved or lifted off their foundations.

This picture has changed with (a) the design trend favoring the rambling ranch-type house, (b) the advent of the light construction systems employed today, (c) the use of low-pitched roofs with wide overhangs, (d) the introduction of large wall openings for picture and display windows as well as sliding doors, (e) the construction of buildings in exposed areas, (f) the rather frequent occurrence of storms, hurricanes, tornadoes, or seismic disturbances in lightly as well as heavily populated areas, and (g) the potential direct or fringe exposure of our buildings to atomic and nuclear blasts.

Parenthetically, it may be noted that high windstorms have been experienced at many locations, with North Carolina, for instance, having been hit by hurricanes just as often as Florida. It is the opinion of some of our weathermen that the traditional paths of hurricanes have changed and that we can expect more of them further inland along the East Coast. Additionally, tornadoes which had been considered farm-country phenomena, have been observed in many areas of suburban growth where a great number of our buildings have been and will be erected and, thus, be in the potential paths of these inland twisters.

Too many homes and industrial and agricultural buildings, or parts thereof, have been lifted or pushed off their foundations during the past two decades. The general public has taken such destruction almost for granted and has considered it inevitable and unavoidable in light of the observed acts of nature. On the other hand, the knowledgeable architect, engineer, code official, and builder often has shuddered in light of the evidence which indicated to him that much of such destruction could have been avoided.

Property damage caused by windstorms, tornadoes, hurricanes, and earthquakes may even increase considerably when buildings will be going up at the rapidly increasing rate we are anticipating and at locations which have not been used for building in the past, provided the needed precautions for safe building are not given due consideration by those who vie with disaster without anticipating it. Therefore, our spotlight focuses on the question whether our buildings and those of the coming generations should be anchored and built more ruggedly to resist windstorms of all kinds — and if that should be the case, how it can be accomplished.

Anchorage is the keyword for building in a storm-resistant manner; that is, anchorage of the roof deck to the rafters, of the rafters to the bond beams, plates and posts, of the bond beams, plates and posts to the walls, of the posts and walls to the floor deck, of the floor deck to the joists, of the joists to the sill, and of the sill to the concrete slab and foundation. With a single link in this anchorage chain missing or out of balance with the whole, disaster is invited in all areas exposed to the elements.

Investigations have been numerous. According to specialists at the University of Maryland and the USDA, for instance, failure of buildings, exposed to hurricanes in Maryland and Delaware, was due primarily to insufficient anchorage to foundations, lack of satisfactory bracing throughout the structure, and lack of sufficient ties to hold its components together. Their prime conclusion was that the most important anchoring was that from the roof to the wall and from the wall to the foundation.

During a recent study by the Federal Housing Administration of tornado-caused damage to buildings in Florida, it was concluded that the roof must be securely fastened to deep bond beams and that these beams must be securely anchored to the concrete slab at all corners of the structure and at the door and window openings, to minimize potential damage to property by tornadoes.

A building protected by its natural environment or artificial wind-breaks may survive a storm, while an identical building only a few yards

distant may be carried or swept away. The tendency to build on summits and in valley bottoms, near or even above rivers, lakes, and oceans — shortly, at locations where areas have been left with little interference by man in awe of nature's power and fear of possible disaster — calls for firm and rigid construction and anchorage all the way to the ground. This is particularly the case for buildings assembled with the advantageous light materials of our age and erected according to the advanced methods of our times as tools of the individual as well as the mass builder, the prefabricator, and mobile-home fabricator. All of them have to be on the alert to make sure that their buildings are anchored properly, since it is their responsibility to see that disaster is avoided whenever possible.

Structural damage generally does not occur until wind velocities exceed 100 miles per hr; and excessive damage usually occurs on poorly built structures when winds reach 125 to 150 miles per hr. Yet, well built frame structures have withstood dozens of hurricanes with winds exceeding 125 miles per hr. On the other hand, the buildings have to resist not only the forces created by winds and gusts, but also by storm surges that cause severe flooding and by the ramming forces of debris, uprooted trees, escaped boats, sideswayed cars, floating lumber, and all kinds of building components.

It must be our effort to build in such a way, without appreciable increase in the cost of construction, that the majority of our buildings to be erected in the future resist forces that can be expected in light of past experience. This challenge is especially important in consideration of the fact that we can anticipate doubling the present number of buildings within the next 30 years. While the old buildings may not be storm-resistant, our new structures doubtlessly should be sufficiently rigid and strong to resist such forces to which these buildings may be exposed.

It is the purpose of this discussion to demonstrate that proper anchorage is one of the prime requirements for storm-resistant construction and should be specified whenever justified.

CODE PROVISIONS FOR ANCHORAGE

Building codes are not designed to provide complete security under extraordinary circumstances. Thus, a wind velocity of 120 miles per hr at 30 ft above ground was adopted as a design criterion in the South Florida Building Code, although winds and especially gusts of higher velocity have been recorded in the area for which this code was designed. Codes are a tool with which to minimize damage expected in the light of past experience. Thus, unjustifiable cost burdens must not be placed on those who do not have to give consideration to special precautions. On the

other hand, where past experience suggests particular care in construction, it would be folly not to pay full attention to it.

An excellent example is the church steeple in Grossweil, West Germany, erected in 1961 in a historically storm-exposed valley where previous steeples and roofs have been sucked off the buildings by storms following the same narrow path of destruction again and again. The new preassembled metal-covered boarded-lumber timber steeple (Fig. 2-1) was placed and anchored securely to its concrete base by all means available. As a result, it has withstood the ravages of repeated "Foehn" storms without the slightest damage.

Most codes provide for anchorage to resist maximum wind velocities of 120 miles per hr, although wind design loads of 150 miles per hr have to be given consideration along at least one coastal area in the United States. Although one national code has ignored completely the effects of high winds, several codes have been specific in requiring resistance to certain wind forces and others call for the use of specific fastening and anchoring devices to resist these forces. At least one code stipulates the incorporation of satisfactory anchoring devices for travel trailers and mobile homes in all spaces used for their parking. In numerous codes, specific construction details have not been incorporated. Therefore, the recent publication of suggested fastening and anchoring details by the U.S. Forest Products Laboratory⁹ has been especially welcomed.

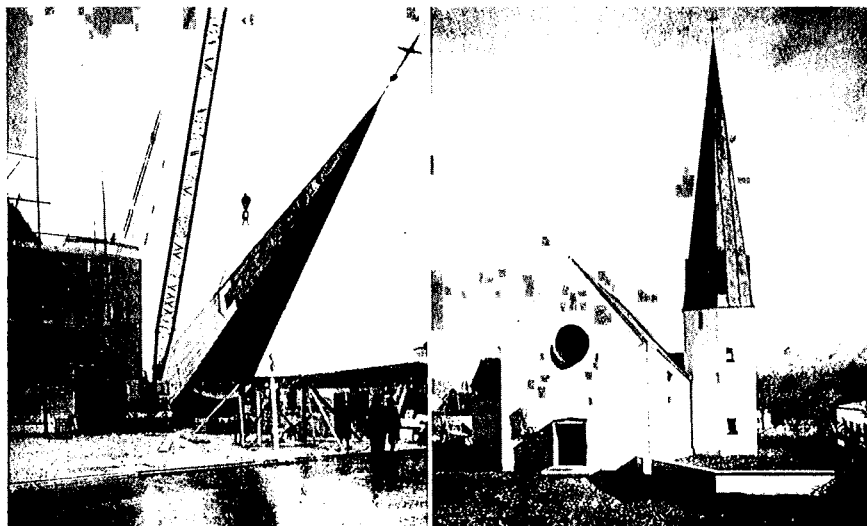


Fig. 2-1—Boarded lumber steeple glued to lumber frame in concrete base providing anchorage for Catholic church steeple in storm exposed valley in Grossweil, Germany

Anchorage to resist seismic forces is, of course, especially important where earthquakes may be anticipated. One code covering earthquake areas requires special anchorage only for major structures and not for one or two-family dwellings, buildings not over three stories or 35 ft in height, and buildings of skeleton frame construction with approved wind and sway bracing, the least dimension of which is not less than 35 percent of their height. Apparently, the anchorage required to resist wind forces is considered sufficient to resist seismic forces in these three cases.

ANCHORAGE DESIGN

Anchorage has to resist sliding forces, overturning moments, and uplift forces in excess of the internal resistance of the structure to such forces. Different codes use different design criteria. The South Florida Building Code, for instance, requires that anchorage has to resist the excess over 50 percent of the moment stability computed from dead load only. Similarly, anchorage has to resist the excess over 50 percent of the dead load where uplift forces exceed 50 percent of the dead load. In contrast, other major codes make reference to two-thirds or three-quarters of the dead load instead of one-half of the dead load.

In designing the mechanical anchoring of walls, all fastenings must have, according to the South Florida Building Code, a supplementary factor of safety of one-half over that required for the design of members. Thus, "the wall fastenings are to be designed for a load of approximately 5 lb per sq ft more than the wall itself."⁶

In line with the results of all investigations made recently, the South Florida Building Code requires that "any anchoring system shall be continuous from the foundation to the roof."⁶ This design procedure should result, of course, in balanced anchorage throughout the structure.

Probably the most detailed published analysis of anchorage-design procedures was made under the auspices of the National Academy of Sciences – National Research Council by the Building Research Advisory Board on behalf of the Federal Housing Administration.² As a result of this study, two methods were presented for the determination of any necessity of anchorage under given conditions. The rapid computation method indicates whether the more exact method of analysis should be carried out.

The BRAB report presents nomographs which make it possible to estimate the stability of a structure of given height, roof slope, and weight per foot of length, with respect to the wind pressure to which the structure is exposed. The forces required to slide the structure off its foundation, to overturn it, and to lift it can be readily determined. Open appendages to the structure, such as carports, garages, and roofed porches

are considered not to affect the stability of the basic structure. Such appendages are quite susceptible to wind pressure and should be anchored in all cases to prevent damage.

Since the BRAB report describes in detail the facts to be given consideration and the methods to be used in determining the structural needs for anchorage, the designer and builder can readily compute anchorage requirements, if they wish or should be required to submit evidence of proper anchorage.

With respect to the extent of seismic forces resulting from earthquake waves, the BRAB report is less specific. The recommendation is advanced that anchorage be employed wherever seismic disturbances can be expected, specifically in all geographic areas in the United States west of longitude 110 deg.

The BRAB report gives also consideration to the anchorage needed to resist any lateral movement of the structure due to earth pressure. Such needed restraint may suggest special anchorage of a structure to its foundation. A foundation wall strong enough to resist bending stresses produced by earth pressures can, of course, be anchored to the foundation to resist these stresses. On the other hand, some of the needed lateral restraint may be secured by anchoring the top of the foundation wall to the superimposed structure. Hence, it is suggested that, under given conditions, backfilling not be allowed before the structure is completed and before the placement of the total weight of the structure onto the foundation wall results in the friction anticipated in the BRAB report. The amount of earth pressure and the weight of the structure on top of the foundation wall, which is required to resist this earth pressure, can be determined for given field conditions from tables found in the BRAB report.

ANCHORAGE TECHNIQUES

To anchor satisfactorily all the residential and other light-frame buildings erected in the United States during a single year might cost upwards of \$60 million. Despite such a cost, the recommendation to provide anchorage — unless evidence is presented that anchorage is not needed — appears to be practical in light of recent developments. They make it possible to anchor these structures to their foundations effectively and efficiently with a minimum of effort and expense.

Bolts and rods

Conventional, relatively time-consuming, hence, costly anchorage consists of embedding $\frac{1}{2}$ in.-diameter bolts 6 to 8 ft on centers in the footing

and foundation wall and fastening the mudsill with large washers and nuts. In exposed areas and earthquake regions, these bolts are to be spaced at least 6 ft on centers and as close as 4 ft from building corners. They are to extend at least 7 in. into cast-in-place concrete and 12 to 18 in. into unit masonry walls and bond beams.

No. 5 steel rods are used to tie masonry blocks and bond beams to concrete footings.

Commercial anchors

Commercial metal anchors or $\frac{1}{8}$ x 1 in. steel straps can be used to anchor lumber framing to foundation walls and sills. These straps are either embedded in the concrete or masonry wall or are anchored to the concrete with suitable fasteners. The straps are fastened to the lumber framing members with nails or bolts. The straps are designed to resist forces as high as 2000 lb. If larger forces are to be resisted, specially designed steel straps and angles may have to be installed.

Powder-actuated studs

A relatively new method of anchoring buildings to concrete is that of driving powder-actuated steel studs or pin fasteners with a gun-like device through the lumber into the foundation. This method of anchorage has the advantage of being positive and direct as in the case of bolts. The zinc-coated austempered or equivalently tempered steel studs and pins have to have a minimum $\frac{7}{32}$ in. shank diameter and must be provided with or driven through standard galvanized washers to be used in earthquake areas. In this case, they have to penetrate the concrete at least $1\frac{1}{2}$ in.; they are to be spaced not less than 3 ft apart; and a minimum of two studs per section of sill or plate is required according to the FHA minimum standards. Any studs which caused spalling of the concrete are to be replaced with additional studs nearby.

The gun, which uses the power of blank cartridges to fire studs or pins, can be a lethal weapon if not handled properly or carefully. Accidents have been reported which were caused by ricocheting fasteners going astray despite the use of safety devices. Yet, the advantages of the powder-actuated tools and fasteners are many, suggesting numerous uses.

According to the BRAB report,² powder-driven fasteners should be set into concrete to a depth of eight times their shank diameter. Then, their permissible withdrawal loads, e.g., in 3000-psi concrete amount to 650 lb for $\frac{5}{32}$ in. diameter fasteners and 1025 lb for $\frac{7}{32}$ in. diameter fasteners; and their corresponding permissible shear loads amount to 540 lb and 1110 lb, respectively. To allow a comparison of these design data with actual test data, the following information is presented: Ac-

According to 25 tests performed during 1960 with 7/32 in. diameter fasteners driven to 1½ in. depth of penetration into 5500-psi concrete,⁴ their average ultimate withdrawal load amounted to 3230 lb and their average ultimate shear load amounted to 4080 lb.

Masonry nails

Hardened-steel, helically or longitudinally fluted masonry nails of light and heavy duty types (Fig. 2-2) were developed during the past two decades,¹ to make available a possibly more economical method of anchoring framed structures to concrete footings or foundation walls. The use of these nails does not require special tools and the nails are relatively inexpensive. They have large diameter, flat, checkered, and slightly countersunk heads and medium diamond or needle points.

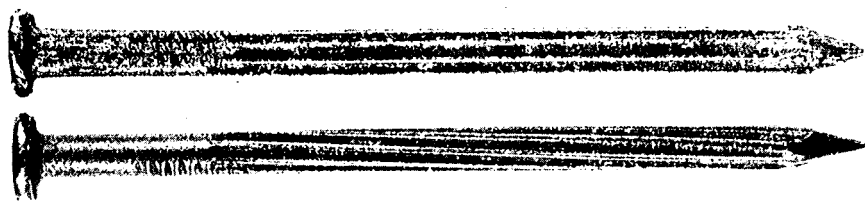


Fig. 2-2—Heavy duty 3½ x 0.250 in. hardened steel masonry nails with 9/16 in. heads and fluted either helically or longitudinally

The light, 2¾ x 0.148 in. nails are used for anchoring load-bearing and nonbearing exterior and interior partition sills as well as sleepers to concrete floors, slabs, and footings. According to the BRAB report,² design loads for these nails, penetrating 1⅛ in. into concrete, amount to one-half of the design values for the 2¾ x 0.150 in. powder-driven studs.

The heavy-duty, 3½ x 0.250 in. nails, with 9/16 in. diameter heads, have been used for numerous anchoring applications and were accepted as early as 1955 for the anchoring of load-bearing and nonbearing interior partitions in earthquake-exposed regions. Subsequently published supplementary design information¹ indicates that these heavy-duty nails are suitable also for anchoring 2 x 6 in. mudsills of exterior load-bearing and nonbearing frame walls in earthquake-exposed regions. According to the BRAB report,² these nails have the same design values as are suggested for the 3¼ x 7/32 in. powder-driven studs.

For the light nail, minimum concrete edge distances of 2 in. and end distances of 3 in. are recommended. The heavy-duty nail may be spaced as near as 3 to 3½ in. from the concrete edge and 6 to 8 in. from the concrete end. The joint stiffness and shear resistance of the latter nail

are, however, 30 percent higher if the end spacing of the nail, driven 3 in. from the concrete edge, is 12 in. instead of 6 to 8 in. The selection of edge and end spacings depend to a certain extent on the concrete since splitting of the concrete must be avoided under all circumstances. Since the holding power of the $\frac{1}{4}$ in. diameter masonry nail is the same as that for the $\frac{7}{32}$ in. powder-driven stud, it can be spaced the same way, that is, 3 ft apart in seismic areas and 4 ft apart in all other areas.

These nails are usually driven with a heavy (3 to 4-lb) hammer, avoiding “pecking” at the nails. The use of excessively brittle nails must be avoided, since they may break during driving or when transmitting shear forces. To eliminate hazards, safety glasses should be worn whenever these masonry nails are driven since a number of heads or parts of heads of brittle masonry nails have “flown off.” They could have caused serious injury under adverse conditions. A few accidents caused by head failures of excessively brittle nails are on record.

Other anchorages

Other universally used techniques for anchoring to concrete require the use of inserts or drilling of the set concrete.⁵ The fasteners falling into this category include calking anchors, mechanically expanded anchors, expansion anchors, manually expanded anchors, wedge-type fasteners, toggle bolts, screw plugs, and nylon fasteners. As previously suggested,⁵ “versatility is obtainable through nylon fasteners, malleable iron anchors with four-way expansion, and compound anchors with lead sleeves and zinc expander cones or nuts. Specialized applications may be met by use of calking anchors, where shallow holes and economy must be considered; lag screw shields with low torque expansion on edges of concrete or where concrete is soft or brittle; and die cast zinc machine bolt anchors with double expansion, where moderate vibration and shock conditions exist and economy is a factor.”

Specific test and design data for the various types of fasteners can be made available by their manufacturers. These specific data cannot be applied to similar products of competing manufacturers and should be restricted to such use conditions as were simulated during the performance of the tests.

ANCHORAGE SUGGESTIONS

As pointed out by Reynolds,³ “the greatest obstacle in preventing tornado damage and casualties is ‘tornado fatalism.’ It has been assumed that no house could withstand direct hits, but the fact remains that much damage can be prevented. Maybe we cannot build to withstand the worst

of the bad tornadoes, but we can build to survive the weaker ones and the marginal areas of the bad ones."

Reynolds noted also that "in the Woodriver tornado of May, 1949, I counted sixteen houses which I judged to have been exposed to winds of about the same intensity. The five bolted (-down) houses remained, although one may have had to be rebuilt. None of the eleven unbolted buildings remained in place and none was repairable." As simple a mechanism as foundation anchor bolts or other anchoring devices can make the difference between safety and total destruction.

The inclusion of $\frac{5}{8}$ in. anchor rods extending from within the foundation all the way through the block wall and bond beam as well as through the plate to which the roof is secured comprises the major part of the CBS (Concrete Block System) construction developed by Florida builders to resist hurricane forces.³ Evidence that this system can be highly effective was presented in the "Operation Cue" in Nevada during May, 1955, where reinforced lightweight-concrete block and precast-slab test houses were erected 4700 ft from ground zero of a 30-kiloton atomic bomb.¹³ These two houses suffered little damage other than blasting out of doors and windows during exposure to an estimated overpressure of approximately 5.1 psi. The performance of CBS houses during the past decade clearly indicates that it would be well to tie down to the foundation all light-weight concrete block structures except those located in highly protected areas. The increase in cost resulting from the inclusion of such anchorage is small in comparison to what is accomplished by such anchorage.

A unique anchorage is provided by a "self-anchored" concrete wall panel developed and tested at the University of Illinois.¹⁰ The panel can be placed on and bolted to the foundation (Fig. 2-3a). Firmer construction can be achieved by placing the bottom edge of the panel in a notch in the footing and tying the panel to the edge of the floor slab (Fig. 2-3b). Such anchorage eliminates the customary concrete columns supporting panels along their sides. If the panel is extended from the floor slab down to the footing, the need for a foundation is also eliminated. By spacing the bolts closer together, the anchorage provisions can be increased to such an extent that adequate strength is provided to resist any reasonably high anchorage requirements. This noteworthy proposal is proof that satisfactory anchorage can be achieved through proper design.

Concrete footings and foundation walls can be anchored to and integrated with the ground in such a way as to resist all forces as well as any undermining by surging water and wave action. The incorporation of a stepped-up footing or foundation-wall top (Fig. 2-4a) as well as the inclusion of concrete wing walls outside the basic house (Fig. 2-4b) can result in highly effective anchorage of the structure.

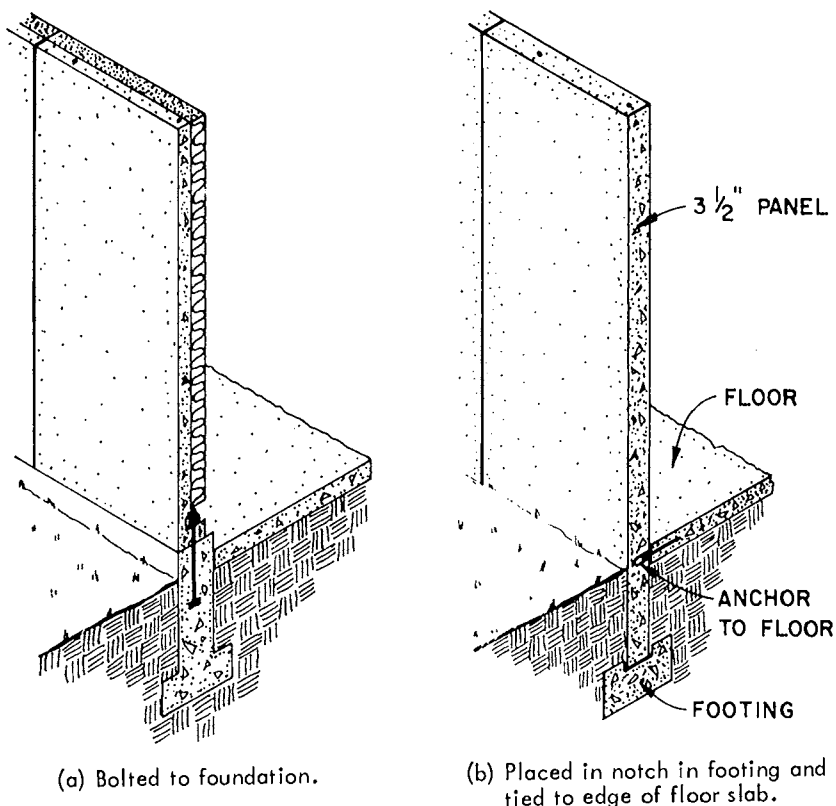


Fig. 2-3—Self anchored concrete wall panel. (l.) Bolted to foundation (r.) Placed in notch in footing and tied to edge of floor slab

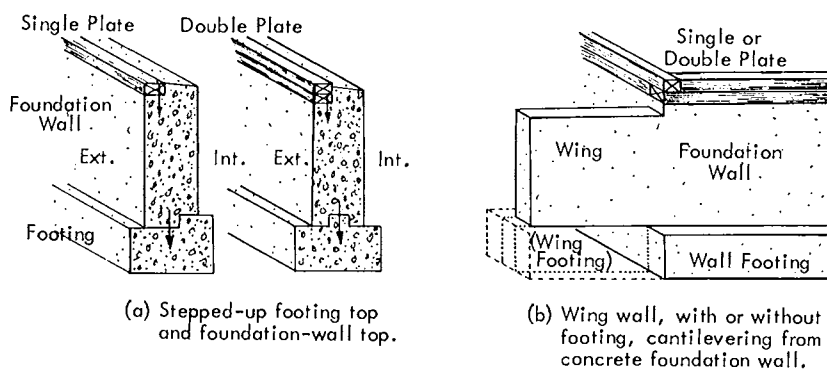


Fig. 2-4—Foundation wall design used in storm resistant construction, providing maximum resistance to sliding forces and washouts

Reinforced concrete wing walls, extending beyond the building proper, can help to keep water from eddying around behind the house, from washing away the soil around the house, and from undermining its footings or floor slab from behind. They can also be helpful in the landscaping of the building. These walls, set in vertical cantilever fashion with or without broad footings but with no support, except where the one wall and footing end ties into the house foundation wall and footing, appear to be especially promising. If designed also to provide longitudinal support, the wing wall can act as an effective buttress absorbing forces in the plane of the foundation wall. This feature is particularly valuable if the foundation wall is provided with many openings and few solid sections. An adequate tie-in between wing wall and foundation wall is, of course, essential. These wing-wall anchors for the building might be used even as symbols of storm-resistant construction.

APPLICATION OF RECOMMENDATIONS

During a determination of the anchorage requirements of a typical lightweight house, designed by Deck House, Inc., of Acton, Mass., it became evident that proper anchorage was a major consideration.¹¹ This house is of considerable appeal because of the incorporation of many of the advanced design and construction principles of our times. Its weight was found to be only 186 lb. per linear foot of longitudinal exterior wall. This low weight was considered insufficient to resist the horizontal wind pressure and other forces which may cause uplift, sliding, and overturning of the building.

The rapid computation method presented in the BRAB report² quickly indicated that special anchorage is needed to withstand wind pressures higher than 17 psf. The minimum uplift resistance along the exterior wall was found to be 207 lb per ft of wall or 19.4 psf of actual roof area. Assuming a coefficient of friction of two-thirds on the weight of the house, its total resistance to sliding forces of short duration, excluding wind pressure, was found to be 174 lb per ft of longitudinal exterior wall. Thus, only 12.5 psf of the total design wind pressure of, e.g., 20 psf in a 25-psf wind-pressure zone could be resisted without anchorage.

Use of $\frac{1}{2}$ in. anchor bolts spaced 6 ft apart made it necessary for the two end walls and the one partition cross-wall to absorb a major part of the horizontal wind forces. Because of the length of the building and the existence of a single cross-wall, the inclusion of short wall sections acting as buttresses appeared to be highly desirable.

To assure satisfactory anchorage against uplift and overturning of the building resulting from a design wind pressure of 25 psf in a 35-psf wind-pressure zone, it was found that the $\frac{1}{2}$ in. anchor bolts spaced 6 ft apart

would have had to be provided with $2\frac{1}{2} \times 2\frac{1}{2}$ in. washers. It was determined, however, that the structure above the sill plate could not resist such a large uplift force without increasing considerably the strength of all joints, e.g., by doubling the number of nails in many joints. Consequently, the use of bolts with extra large washers was not justified. On the other hand, the use of the above anchor bolts provided with standard 2×2 in. washers resulted in a 28 percent higher uplift resistance than was required to resist forces caused by a 20 psf wind force.

In light of these findings, it became evident that the structures could be designed and anchored without excessive increase in cost to resist a 20 psf wind force in a 25-psf wind-pressure zone. To increase the storm resistance of the structures to withstand higher wind pressures in exposed areas, the incorporation of four features was suggested:

1. Step up the top of the concrete foundation wall in such a way that the sill plate cannot slide in the direction of the interior of the building, as shown in Fig. 2-4a. Such a procedure provides optimum resistance to horizontal forces by wind, water, wave, and seismic forces
2. Design and build the partition walls to act as rigid diaphragms
3. Reinforce exterior walls, longer than 24 ft without lateral support by partition walls, with short wall sections acting as buttresses which are anchored well to the exterior wall, at the bottom to the concrete foundation, and at the top to the structural framing
4. Add wing walls in extension of the exterior foundation walls, as shown in Fig. 2-4b, to act as effective buttresses and to prevent washouts in case of exposure to potential floods and/or waves.

CONCLUSIONS

By proper anchorage, reinforcing the joints, using improved fasteners, and strengthening the design, better storm-resistant structures can be built. Some of these improvements result in negligible added costs, whereas others can increase the cost of building in such a way that the builders have to be firmly impressed of the worth of these improvements and their value to the occupants of the structures. These cost increases should not be solely subject to economic considerations. They must be looked at in light of the security they provide and the assurance that individual and national wealth is protected so far as is practical by averting disaster in many cases of emergency.

Storm-resistant construction, in contrast to storm-proof construction, is possible. It is practical, justified, and should be made obligatory in most areas of the United States, since no assurance can be given that

they may never be affected by forces resulting from exposure to the ravages of the elements or man-made blasts.

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Classification of Fasteners for Concrete

By BEN L. BIRD

There are six general considerations for fasteners: (1) load level, weight held; (2) load condition — dead, variable, vibratory, shock; (3) base material; (4) atmospheric condition; (5) in-place cost and (6) simplicity of design.

No one fastener is best under all circumstances. Of the nine general fastener classes, most are best under a limited range of conditions. A few types can perform reliably under a rather wide variety of conditions. This paper details the nine classes of fasteners and describes the installation, performance data, application range, and components of each.

Keywords: anchoring; anchors; bolts; concrete blocks; concretes; costs; drilling; expansion bolts; fasteners; inserts; lag bolts; loads (forces); nails; precast concrete; screws; studs; toggle bolts.

■ THE TOTAL CONCEPT OF FASTENING to concrete is affected by two general sets of circumstances: (1) Application requirements and (2) Type and condition of concrete. Prior to considering fastener classification or selection of fasteners for application to concrete, the following six general requirements for these fasteners must be understood. They are important to both the specifier and the installer.

GENERAL REQUIREMENTS

Load level — The amount of weight to be held by each fastener in a given application. It can vary from a few ounces to several tons.

Load condition — The outside force or forces potentially to be applied to the fastener (or fastening) after installation. These are: (a) dead loads; (b) variable loads which occur when outside forces are applied, such as in a hand railing, where the live load is a variable load when a pedestrian leans against it; (c) vibratory loads which can involve a high rate of impact applied over more or less lengthy periods of time, such as in a blower or electric motor mounting; and (d) shock loads

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which are experienced when a high degree of impact is imposed on the fastening, for example when a motor vehicle strikes a dock bumper.

Base material — The holding material in which the fastener is to be installed, falling into the following general categories: (a) solid materials, such as cast-in-place concrete; (b) hollow materials, such as concrete block; (c) hard materials, such as high density concrete; and (d) soft materials, such as sandstone.

Atmospheric condition — Elements in the atmosphere such as moisture, salt (coastal air), chemicals (industrial atmosphere), and heat or cold resulting in expansion or contraction.

In-place cost — Installed cost of the fastener, which includes the price of the anchor, tools, and labor, including layout time to be added for some fastener types.

Simplicity — This requirement is difficult to define. A fastener of simple design easily installed, will provide assurance that it will attain maximum performance under the service conditions encountered.

TYPES OF CONCRETE

The type of the concrete used is a part of the third general requirement, introducing a variety of considerations for fastener specification or installation. For fastening purposes, the types of concrete can be divided into (a) solid concrete and (b) hollow concrete.

Solid concrete can be of either low or high compressive strength. Variations in concrete, regardless of compressive strength, result from the types of aggregate used and have a direct bearing on fastener selection and/or installation procedures. Different problems in selection and/or installation develop when prestressed or reinforced concrete are encountered. Precast slabs, air-entrained, high-early, or soft-subbase concretes add to the complications in selecting and/or installing fasteners.

Hollow concrete is found in certain types of precast members and in concrete blocks, and poses specific problems for those charged with the

responsibility of specifying and installing. Similar conditions can be encountered in solid concrete where voids exist.

CONDITION OF CONCRETE

The condition of the concrete, for the purpose of fastener specification or installation, should be considered with the following aspects in mind. Designers and developers of fasteners for concrete must endeavor to meet these basic requirements.

Age: Concrete can be green and weak, or aged where it has acquired added compressive strength.

Brittleness: It can be caused by aging or such other influences as weather and chemicals.

Surface concrete: Aggregate is often found near the surface, particularly in ceilings which present problems for the installer.

Unconfined concrete: Slabs, such as in a balcony or columns, where fastenings are to be located near edges of concrete, demand different selection than confined concrete where edges are not encountered.

FASTENER DESIGN

In design the following considerations are of particular importance:

Load levels — Are met, basically, by the required length and diameter of the fastener. The deeper a fastener is set in concrete, that is, as the length of a fastener is increased, the amount of concrete which may be displaced (in the event of failure of the fastener) will be increased. Likewise, concrete displacement and holding power are increased as the diameter of the fastener is increased.

Load conditions — Are met in a variety of ways, basically by the method of expansion and/or by the materials used in manufacture. A fastener that expands by drawing the expander into the sleeve (or shell) tends to tighten further as loading is imposed. Such a fastener can also be retightened. A fastener that is expanded by driving the shell over an expanding element, attains maximum holding power during installation. This fastener does not increase its holding power as the load is imposed and it cannot be retightened.

The fastener materials should be compatible with concrete. For instance, lead is soft and will not erode concrete; however, it has little tensile strength. Steel has high tensile strength; however, being harder than concrete, steel can erode the concrete and cause loosening. Zinc and malleable iron have desired tensile strengths and are compatible with concrete. Nylon has moderate strength, but is highly compatible with concrete. Therefore, zinc and malleable iron are desirable as single ma-

materials for medium to heavy loads. Lead and steel are considered undesirable as single materials. A combination of malleable iron or zinc and lead can be desirable. Nylon, as a single material, would be desirable for light loads.

Base materials — Because of a variety of conditions within the hollow and solid classifications, fasteners are required that: (a) expand and hold under compression in solid material, and (b) bend and deform by expanding in hollow materials, voids, and soft subbase materials. Most fasteners qualify for solid materials. Others have toggle or riveting actions and meet the requirements of hollow materials. A few types of fasteners have both toggle action and the ability to develop compression in expansion and can, therefore, be used in either solid or hollow concrete.

Fasteners that have split shells and expand by drawing the expander element into the shell, can be used in both hollow or solid concrete. They are made of zinc, malleable iron, or sheet metal, in medium to heavy classes. For light load applications, they have nylon or rubber shells with threaded steel expanders. Unconfined concrete applications are best fulfilled by low torque fasteners. They expand by threading a screw into the shell. For medium to heavy loads they are generally zinc shells. For light loads they incorporate nylon or lead shells.

Atmospheric conditions — Difficulties resulting from poor atmospheric conditions are best overcome by fasteners having zinc shells or lead sleeves with zinc expander elements of medium to heavy classifications. Light load classes of fasteners having nylon shells are highly desirable. Nylon, being inert, is not attacked by foreign elements in the atmosphere. Steel is least desirable from this viewpoint due to its vulnerability to corrosion. Even when plated, many of the steel fasteners are subject to high corrosion rates. Part of the plating is often removed during installation and/or raw steel is exposed during expansion.

In-place cost — It is influenced by the fastener price, the tools required, and drilling time in the concrete. Therefore, if more than one fastener meets the four requirements previously given, the lowest in price should first be considered. However, some fasteners require special purpose tools for their installation, which can add to their total cost. An example is the displacement fastener that requires a special cartridge tool (gun) or fastener holder. In the latter case, special hammers are required. These systems can, however, be used to considerable advantage when air or electric power is not readily available.

When power is available, general-purpose electric rotary hammers or hammer drills can provide economical drilling means. This is particularly true with late model rotary hammers that can provide a $\frac{3}{4}$ in. hole 1 in. deep in as little as 5 sec in average (3600 psi) concrete with limestone aggregate. Drilling time may, however, increase 20 per-

cent on the average, when riverbed aggregates are used. Most rotary hammer carbide bits permit drilling of over 2500 holes in limestone aggregate. Hole production in harder aggregates can, however, be cut by 20-30 percent, depending on the hardness of the aggregate.

Variations in concrete, that contribute to inconsistent drilling time, can also work to the disadvantage of fasteners that do not require concrete drills. Thus, aggregate can cause deflection of displacement fasteners resulting in loss rates of 10 percent and more. Furthermore, hard aggregate can completely preclude use of these fasteners. Steel shell (self-drilling) anchors drill their own hole in average concrete. Extremely poor conditions can result in the inability of this type of fastener to complete the drilling operation.

Costs can best be estimated with those anchors that provide the greatest degree of consistency in installation plus reliability of performance after their installation.

Simplicity — Consistency of installation and reliability in performance depend to a great extent on simplicity in fastener design and installation procedure. Such simple fasteners reduce the amount of judgment and/or the special skills required of installers. Some types of fasteners require precise drilling to attain the hole dimensions necessary for reliable performance. Others, which have a high degree of expansion, can compensate for inconsistent hole dimensions and deliver an acceptable degree of reliability.

Generally fasteners that can be used in both hollow and solid concretes, will permit the installer to use the same procedure in all applications where the fastener qualifies. This assures improved workmanship and reliability of installation.

TYPES OF FASTENERS

Fasteners for concrete can be divided into the following nine classes. Most of the classes of fasteners were designed to perform with reliability in a limited range of conditions. A few of them can perform reliably in a wider variety of conditions.

Caulking anchors

Caulking anchors are available in three types: (a) machine screw anchors (single unit); (b) machine bolt compound anchors (multiple unit); and (c) stud bolt anchors (single unit) (see Fig. 3-1).

Components — Lead sleeve and a threaded zinc, brass, or malleable iron expander element comprise a single unit. Compound anchors have two or more single units. Flush types have one threaded expander whereas stud types, which are set over a bolt with the head inserted first,

are furnished with unthreaded expanders. Stud-bolt types have a single unthreaded unit assembled over a smooth taper headed bolt.

Installation — Accomplished by expanding (caulking) lead sleeves over the expander element in a hole pre-drilled to manufacturer's specifications. Caulking is done by hammering with a caulking tool.

Application range — These fasteners can be used in hard or soft, solid materials, attaining holding power by compression of lead between the expander and the hole wall. The ability of lead to flow into irregularities of the hole makes caulking anchors desirable for dead and variable loads in single unit types. Compound types qualify for all four load conditions described previously. They have excellent corrosion resistance characteristics. They develop high holding power in relation to hole depth requirements.

Size and performance data — Machine screw types are available in 6-32 to $\frac{3}{4}$ in. screw sizes and their holding power ranges from 500 to 8700 lb. Stud bolt types range from $\frac{1}{4}$ to $\frac{1}{2}$ in. sizes and develop holding power from 2000 to 5600 lb. Compound anchor sizes have $\frac{1}{4}$ to $1\frac{3}{4}$ in. bolt diameters, developing holding power of 3000 to 90,000 lb.

Mechanically expanded anchors

Mechanically expanded anchors have within their class five types: (a) single cone; (b) double cone; (c) closed back; (d) four legged closed end; and (e) stud bolt. All are machine bolt anchors (see Fig. 3-2).

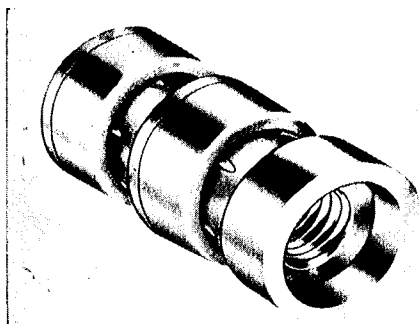


Fig. 3-1—Caulking anchor

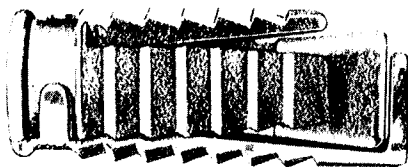


Fig. 3-2—Mechanically expanded anchor

Components — They include (a) shell and threaded expander cone (single and closed back); (b) shell with lower threaded cone; (c) shell with upper unthreaded cone (double); (d) shell having four legs with one leg turned under to form a closed end; and (e) threaded expander,

sleeve, shell, and taper end stud-bolt (stud-bolt type). The first four types are manufactured in die-cast zinc or malleable iron (closed back and four section). The stud bolt types are generally fabricated from sheet metal.

Installation — The anchors are dropped or tapped (with light hammer blows) into predrilled holes, drilled to manufacturer's specifications. After the fixture is positioned, a machine bolt is inserted through the fixture and threaded into the expander. Expansion is accomplished by tightening the bolt and drawing the expander into the shell (in the direction of load application). Stud-bolt types are dropped into a pre-drilled hole after the fixture is positioned. The tapered end of the bolt is drawn into the shell by tightening a nut on the bolt.

Application range — All of these anchors can be used in hard or soft solid concrete. The four-section type anchor can also be used in hollow core concrete as can the stud-bolt anchor. However, care must be exercised in turning the stud-bolt to prevent twisting the shell. Single, closed-back and four-section types respond favorably to dead, variable, and vibratory loads. Doubles are recommended for all four load conditions described. Stud-bolt types are suitable for dead and variable loads.

Size and performance data — Singles are available in short or long shield varieties. Long shields are generally $\frac{1}{2}$ in. longer. Bolt sizes range from $\frac{1}{4}$ to 1 in. (the short variety starts at $\frac{5}{16}$ in.). Holding power ranges from 2250 to 11,000 lb (for long shield) and from 4000 to 10,000 lb (for short shield).

Doubles start at $\frac{1}{4}$ in. and are available up to 1 in. bolt size. Holding power ranges from 2500 to 12,500 lb. Closed-back sizes and holding power ranges are identical for the long-shield singles. Four-section anchors range from $\frac{1}{4}$ to 1 in. bolt sizes and develop holding power of 2000 to 11,000 lb. Stud-bolt anchors are available in $\frac{1}{4}$, $\frac{3}{8}$, $\frac{1}{2}$, $\frac{5}{8}$, and $\frac{3}{4}$ in. diameters. Their holding power ranges from 400 to 4400 lb.

Expansive anchors

Expansive anchors are here confined to those that accept a lag-screw and lag-screw shields (see Fig. 3-3).

Components — Expansive anchors are comprised of a shell having an internal thread that conforms with the configuration of a lag-screw. They are manufactured from zinc alloy or, in special sizes, from malleable iron.

Installation — It is simply a matter of dropping (or tapping) the shell into a hole drilled to manufacturer's requirements; then, placing the fixture in position, a lag-screw is inserted into the shell and tight-

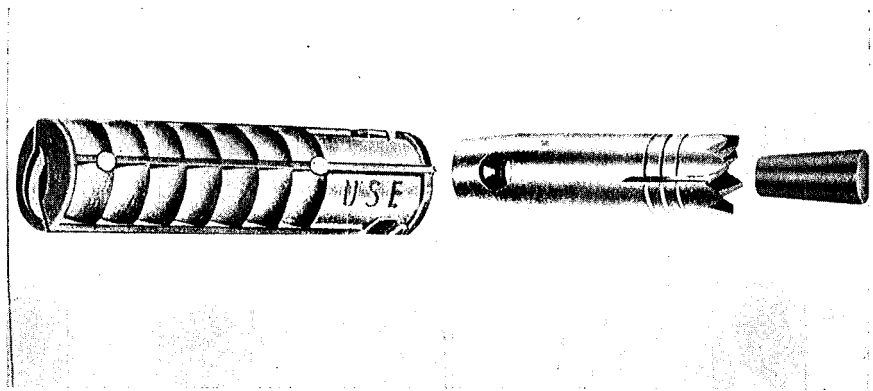


Fig. 3-3—Expansive anchor

Fig. 3-4—Manually expanded, self-drilling anchor

ned. Maximum expansion (and holding power) is acquired by completely threading the screw into the shell. Therefore, expansion and holding strength are not dependent on the torque applied.

Application range — Anchors of this type can be used with all solid materials. Due to their low torque requirements, the expansive anchors are desirable in fastening near edges of slabs and in soft or brittle materials. Manufacturers offer short and long shields for specific screw sizes. Long shields are generally $\frac{1}{2}$ in. longer and are recommended for materials of relatively low density for development of holding power comparable to that of short shields in denser concrete. Short shields, therefore, can reduce drilling time, without materially reducing holding power in hard concrete. All of these fasteners are recommended for dead and variable loads. Some types can be used in vibratory loads.

Size and performance data — Lag-screw shields made of zinc are generally available for screw sizes of $\frac{1}{4}$ to $\frac{1}{2}$ in. The short-shield holding power ranges from 1000 to 5500 lb in average concrete; whereas long shields will develop 1250 to 6800 lb in the same material. Expansive malleable iron anchors are now available in short, long, and extra long lengths accepting screws of $\frac{3}{8}$ to 1 in. in diameters. Their holding power ranges from 3300 to 10,000 lb.

Manually expanded anchors

Manually expanded anchors consist of: (a) self-drilling anchors; (b) steel shell drop-ins; and (c) solid steel stud-bolt anchors (see Fig. 3-4).

Components — Self-drills are comprised of a steel shell, having cutting teeth at the lower end and a steel expander plug over which the shell

is expanded. Steel shell drop-ins are similar to self-drills, except the shell has no cutting teeth. Stud styles are furnished with the upper (solid) end of the shell threaded and the lower end bored out to accept an expander plug. These fasteners are case-hardened and plated, although some types of drop-ins are not heat treated.

Installation — Self-drilling types are available in two head styles: (a) tapered heads and (b) flush heads. All of these are core drills. The tapered heads are inserted in electric or air-hammer chucks and will drill their own holes by manually swiveling the chuck while employing the hammering action of power hammers. Flush heads are threaded onto hand drivers and will cut their own holes by hand rotation and hammering with a machinist's hammer. Stud-bolt types are inserted into predrilled holes, drilled to manufacturer's specifications.

All three types are expanded by hammering the shell over the expander plug. Tapered head types are expanded by hammer action of power hammers (without rotation). When set, the taper head is snapped off for flush installation. Flush-head types, stud bolts, and steel-shell drop-ins are set by hand hammering the shell over the expander plug, using a hand driver or setting tool. It should be noted that the expansion of fasteners of this classification is accomplished in the opposite direction of load application.

Application range — All fasteners of this classification are designed for hard, solid concrete. Self-drilling types perform well in limestone aggregate concrete but can be problematical in concretes made with riverbed, flint, and some other aggregates. Steel-shell drop-ins and stud-bolt types of this classification require relatively precise hole dimensions. As a consequence, they are recommended for dead and variable loads only.

Size and performance data — Most lines of self-drilling bolts range in size from $\frac{1}{4}$ to $\frac{7}{8}$ in. in snap-off head types and from $\frac{1}{4}$ to $\frac{3}{4}$ in. in the rod-hanger and flush-head type. Drop-in bolt sizes range from $\frac{1}{4}$ to $\frac{5}{8}$ in. and stud-bolts from $\frac{1}{4} \times 2$ in. to $\frac{3}{4} \times 6$ in. Holding power ranges from 3660 to 19,560 lb (self-drills); 2750 to 9500 lb (drop-ins); 400 to 4400 lb (stud bolts).

Displacement fasteners

Displacement fasteners require no predrilled holes and include the following types: (a) drive pins (nail), (b) threaded studs, (c) eye pins, and (d) smooth post (wire loops) (see Fig. 3-5).

Components — Displacement fasteners are cold-headed from steel wire and specially heat treated to attain a high degree of hardness with sufficient ductility to preclude breaking. Most have plastic tips or steel

washers for holding devices in tools and to guide them perpendicular to the surface during driving.

Installation — The driving force for penetration of the concrete is provided by cartridges or caps (powder-actuated systems) or hammer blows (hand-driven systems). Two types of tools are now available in cartridge systems: (a) low-velocity tools wherein the force of a detonated cartridge is applied to a piston and the piston drives the fastener into concrete; and (b) high-velocity tools wherein the energy of a detonated cartridge is employed to drive the fastener in “free flight” down the barrel of the tool into concrete.

The latter system is almost identical in principle to that of a fire-arm. At least six power levels of cartridges are available to attain varying penetration forces to compensate for different hardnesses of concrete. Further adjustment in penetration force can be accomplished by positioning fasteners away from the breach of the tool. All tools are designed to prevent firing unless they are held within a few degrees (usually 8 deg) from the direction perpendicular to the surface of the concrete, thus assuring straight penetration.

Hand-driven systems depend on a few blows of a machinist's hammer applied to a piston-type driver within a special hand tool. Held in the direction perpendicular to the surface of the concrete, the fasteners can be driven into the concrete.

Powder systems require trained operators and hand driven systems require skill attained through practice.

Application range — These systems can be used to advantage in solid concrete of average compressive strength. Hard or heavy aggregates can cause deflections, thus contributing to lost or unreliable fastenings. Both powder and hand-driven displacement fasteners can be considered for dead and variable loads.

Size and performance data — Fasteners designed for powder-actuated systems are available in head diameters of $3/16$, $1/4$, and $3/8$ in. Their lengths vary from $1/2$ to 3 in. Holding power ranges from 1700 to 4800 lb. Hand driven fasteners range from $1/8$ to $1/4$ in. head diameters and from $1/2$ to 3 in. long. They develop holding power of up to 400 lb in average concrete.

Wedge-type fasteners

Wedge-type fasteners are of rail-type design with a round head. (Fig. 3-6).

Components — The pin-type fastener has its shank split approximately one-half of its length. Splitting is accomplished by bending one-

half of the shank along the longitudinal axis in a downward direction and the other half upward to form a wedge.

Installation — The fastener is driven through a hole in the fixture and into a predrilled hole in the concrete.

Application range — Their use is limited to “nailing” fixtures to solid concrete. These fasteners are recommended for dead and variable load conditions.

Size and performance data — They are available in shank diameters ranging from 3/16 to 1/2 in. and lengths of 1 to 6 in.

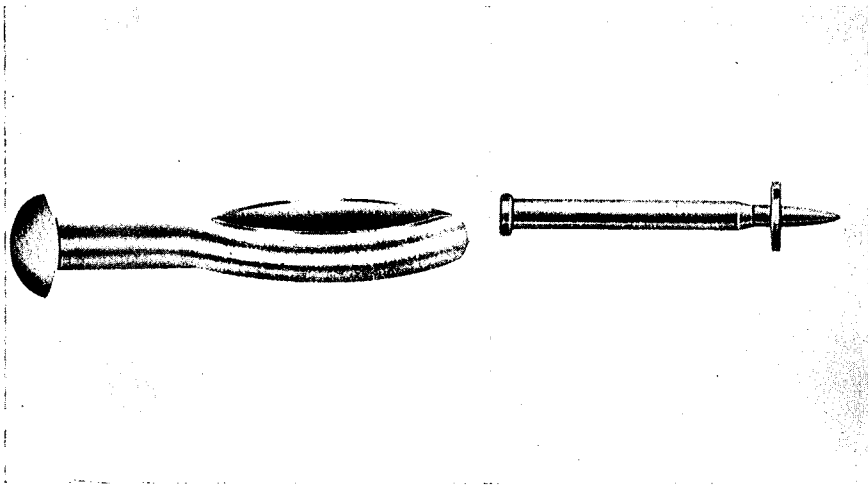


Fig. 3-5—Drive pin for displacement fastener

Fig. 3-6—Wedge type fastener

Toggle bolts

Toggle bolts fall into two general categories: (a) spring-wing types and (b) gravity types. They are available with machine-thread screws having flat, mushroom, or round heads (see Fig. 3-7).

Components — Spring-wing toggle bolts consist of a two-wing sheet metal head assembled over a wire spring (for expansion) and a threaded nut. A machine-thread screw is then threaded into the wing nut. Some types of spring-wing toggles have heads fabricated from heavy gage wire. Gravity-type toggle bolt heads are fabricated from sheet metal and assembled over a threaded nut. One wing is longer and heavier than the other. A machine-thread screw is threaded into the wing nut. The stud-type gravity toggle has a flattened bolt riveted to the toggle head.

Installation — The toggle screw is inserted through the fixture and then threaded into the toggle head nut. In the case of spring wing types,

the wings are folded back and then pushed through a predrilled hole in the hollow-core material. The wings will snap open in the core and the entire assembly is tightened by threading the screw into the toggle nut until the assembly is snug. The same procedure is followed with the gravity types except the wing is turned under and parallel to the screw. It is then inserted into the hole, with short wing first, so that the longer, heavier, wing drops into position before the screw is tightened.

Application range — These fasteners are designed for use in hollow-core materials only. They are recommended for dead and variable loads.

Size and performance data — Spring-wing types are available in bolt sizes ranging from $\frac{1}{8}$ x 6 in. to $\frac{1}{2}$ x 8 in. The bolt sizes of stud-type gravity toggles start at $\frac{3}{16}$ x 6 in. and go to $\frac{1}{2}$ x 6 in. Holding power of spring wings ranges from 64 to 800 lb; that of regular gravity types ranges from 32 to 352 lb; and that of stud-bolt gravity toggles ranges from 200 to 300 lb.

Screw plugs

Screw plugs include fiber, lead, and a wide variety of plastic anchors.

Components — Fiber plugs generally are comprised of a lead core with a jute fiber sleeve woven around it. Other screw plugs are simple molded plastic or lead one piece sleeves, with two vertical expansion slots.

Installation — Plugs are inserted into holes drilled to manufacturer's specifications. After the fixture is positioned, a wood screw is inserted through the fixture and threaded into the plug with a screw driver. Holding power of screw plugs is developed by compression of the sleeve

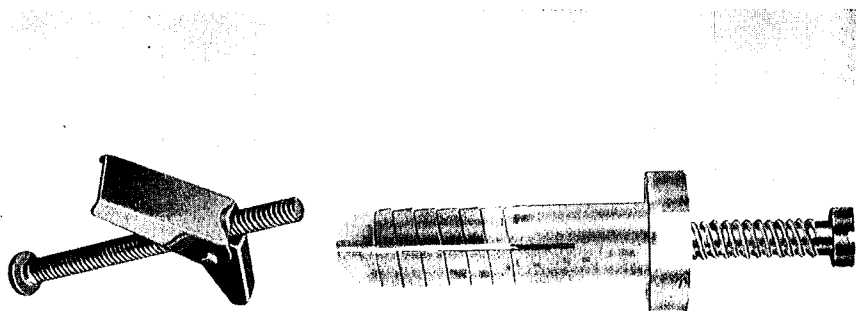


Fig. 3-7—Toggle bolt having spring activated wings

Fig. 3-8—Nail anchor of the nylon shell type

between the screw and the wall of the hole. Therefore, hole dimensions, both in length and diameter, are critical.

Application range — The screw plug application is limited to solid materials. Optimum compression is attained in hard solid materials. They are recommended only for dead and variable loads.

Size and performance data — Lead anchors will accept wood screws from No. 6 to No. 24 and develop a holding power of 200 to 2750 lb in average concrete. The screw sizes of plastic plugs range from No. 4 to No. 18 and hold from 12 to 300 lb in average concrete. Fiber plugs are available for wood screws ranging from No. 6 to No. 20 and have a holding power range of from 220 to 1132 lb.

Nail anchors

Nail anchors fall into two distinct categories: (a) metal shell nail anchors for hard solid materials, and (b) nylon shell anchors for hard or soft solid materials and hollow-core materials (see Fig. 3-8).

Components — Metallic nail anchors are generally die-cast aluminum or steel shells with steel expander nails. The shell has two expansion slots that expand sufficiently, when the nail is driven home, to develop a compressive force in the surrounding solid material. Nylon fasteners have threaded drive screws with nylon shells. The shells have two expansion slots arranged in such a way that compression is developed in solid material when the drive screw is seated by a hammer. In hollow-core materials, the resilience of nylon permits toggle action of the legs to make them an ideal fastener in hollow applications.

Installation — This class of fastener permits prepositioning of the fixture. Holes can be drilled in the concrete or other base material using the fixture as a template. The fastener is then inserted through the fixture and the nail or drive screw seated with a few taps of a hammer. The flow characteristic of nylon shells permits easy retractability of the drive screw and removal of the fastener.

Application range — Metal nail anchors are designed for solid concrete only and are recommended for dead and variable loads. Nylon fasteners can be used in solid or hollow materials. Because nylon is compatible with all classes of masonry and is a resilient material, this type of fastener is recommended for all four load conditions. Nylon is inert and therefore ideal for all atmospheric conditions.

Size and performance data — Metal nail anchors are available in $\frac{1}{4}$ in. shank diameters and lengths of $\frac{3}{4}$ to 2 in. Holding power ranges from 600 to 1200 lb. Nylon fasteners are offered in $\frac{3}{16}$ and $\frac{1}{4}$ in. shank diameters and in lengths from $\frac{1}{2}$ to 2 in. They develop holding power ranging from 65 to 360 lb.

CONCLUSIONS

The requirements imposed on fasteners for concrete and the wide range and conditions of concrete, create complex problems for anyone responsible for specifying or using fasteners. Because there are nine classifications of fasteners and many types and sizes within each classification, it might be concluded erroneously that the specification writer should allow selection of appropriate fasteners to remain a job-site responsibility. There is currently, no single fastener that can meet all six requirements and at the same time satisfy the wide variety of job-site conditions. However, there is a system available that can simplify specification writing and assure use of reliable fastenings, although it does not give consideration to all types of fasteners available:

1. For light loads, up to 70 lb safe working load per fastener, use nylon nail drive-type fasteners.

2. For medium loads, up to 3750 lb safe working load per fastener, use four legged mechanically expanded anchors of die-cast zinc or malleable iron.

3. For extreme loads, up to 22,500 lb safe working load per fastener, use compound machine-bolt caulking anchors having lead sleeves and either die-cast zinc or malleable iron expander elements (see Table 3-1). (Note: Computation of all safe working loads is based on one-quarter of the ultimate holding power or pullout load of the anchor.)

TABLE 3-1 — ANCHOR TYPE REQUIREMENTS

Requirement	Nylon drive nail fastener	Four section machine bolt anchor	Compound machine bolt caulking anchor
Load level	Up to 70 lb safe working load	Up to 3750 lb safe working load	Up to 22,500 lb safe working load
Load condition	a, b, c, d*	a, b, c*	a, b, c, d*
Base material	All types	All types	Solid concrete (only type involved in this load level)
Atmospheric condition	Inert	Highest resistance in its class	Highest resistance in its class
In-place cost	Lowest	Lowest in class	Not a major factor in this load level
Simplicity	Three-step installation	Three-step installation	Not a major factor in critical applications

*a-Dead load; b-Variable load; c-Vibratory load; d-Shock load.

Past Performances of Certain Fasteners and Required Research and Development

By J. E. FRANCIS

Performance characteristics of powder driven fasteners installed in hardened concrete ranging in age from 30 years to 30 days indicate that failure in both shear and tension is apparently the direct result of frequent misapplication.

Under controlled conditions, using hydraulic pull-testers, the type of aggregate used determined the reliability factor. Test findings from 1960 through 1964 indicated performance reliability doubtful, with few acceptable applications.

Definite recommendations are made for coordinated design criteria and the compilation of test data in manual form.

Keywords: aggregates; concretes; failures; fasteners; hardened concrete; hardness; loads (forces); penetration; powder actuated tools; pullout tests; safety; studs.

■ CERTAIN FASTENERS MAY BE DEFINED as powder-driven, hammer-driven, or drilled type fasteners that are installed into hardened concrete.

Past performances of certain fasteners used in structures designed and constructed under the General Services Administration's direction and authority gave sufficient cause for several investigations and studies to be launched. In 1960 a report¹ appeared recommending that fasteners be limited to inserts that are placed in the concrete forming prior to placement of the concrete.

An attempt was made in 1961 to further evaluate powder-driven fasteners but was discontinued due to a high rate of failure that exceeded 33 percent.

A successful study undertaken in 1962 by the Research and Standards staff of the Mechanical and Electrical Branch, Public Buildings Service² was concluded in 1964 with recommendations limiting the use of powder-driven fasteners to net loads not exceeding 50 lb per fastener in areas receiving ceilings. Also, it recommended that powder-driven fasteners

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not be permitted for the hanging of items that must be located exactly in a predetermined position.

Further consideration will be given here in a review and correlation of the latter study with other existing data and knowledge.

Use of fasteners that can be installed in hardened concrete offers many advantages and often reduces the area of responsibility to the trade installing the item or material being secured. The development of basic design criteria for their use should receive serious consideration. A review of existing data and knowledge as constituted by this study will show that considerable cooperative research is necessary before a comprehensive design manual for the selection and application of fasteners installed into hardened concrete can become a fact.

PERFORMANCES AND CHARACTERISTICS

Evaluation tests by public building service

The 1960 report,¹ was a study of the application and effectiveness of powder-driven fasteners. Purposes of this study was to determine if such fasteners should be permitted in the construction and maintenance of Public Buildings Service projects. The report consisted of findings from site investigations of projects where powder-driven fasteners were being used, and interviews with officials of other agencies such as the Department of the Army, the Veterans Administration, and the Federal Housing Administration. The findings of this study indicated that this type of fastener was unsatisfactory for the following reasons: (1) frequent misapplication, (2) lacked positive anchorage, (3) failures in both shear and tension.

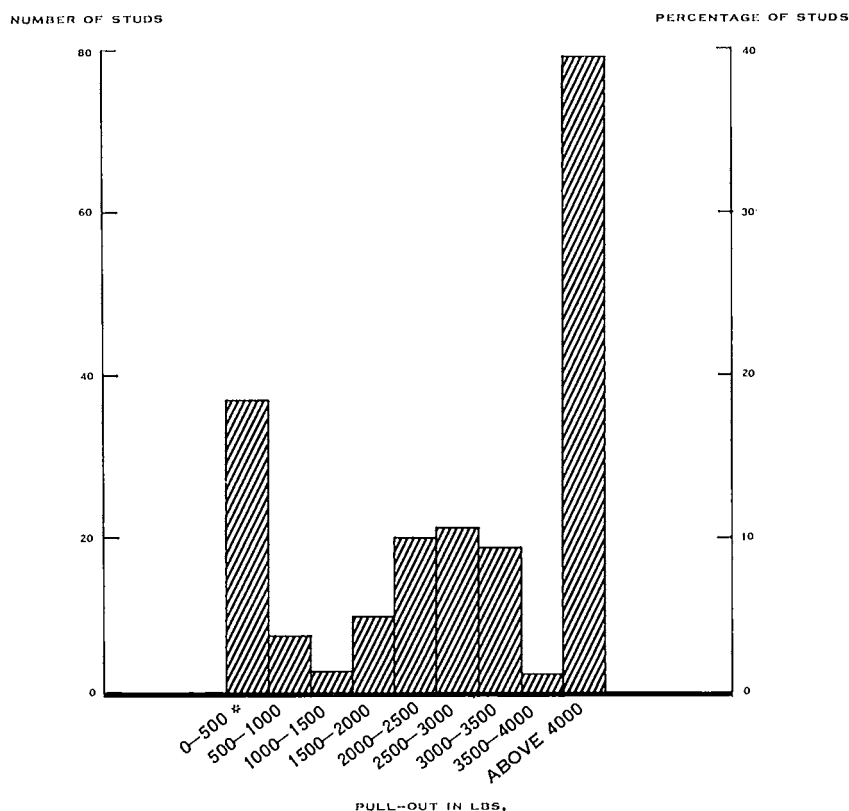
An attempt was made in 1961 to evaluate powder-driven fasteners and tests were started in cooperation with manufacturers. These tests were discontinued because of the high rate of failure.

In 1962 a study was undertaken to evaluate powder-driven fasteners in comparison with other types of fasteners such as drilled fasteners, in-

serts, and the like. This study was undertaken in the belief that improvements made in the selection of studs and powder charges, since the testing attempts in 1961, might show improvement in reliability. It was anticipated that satisfactory test results would lead to the permissible use of powder-driven fasteners in Public Buildings Service construction and maintenance projects wherever they were more economical.

Four buildings were selected for these tests. The concrete in these buildings ranged in age from 30 years to 30 days. The design strength of the concrete was approximately 2000 psi in the three older buildings and 3750 psi in the newer building. Test areas were selected and a rectangular grid pattern established so as to avoid known locations of underfloor ducts.

The results of these tests are summarized in Fig. 4-1.



* INCLUDES ALL FAILURES, SUCH AS UNDER-PENETRATION, OVERPENETRATION OR PULL-OUTS UNDER 500 LBS.

Fig. 4-1—Summary of pull-out data for all studs fired

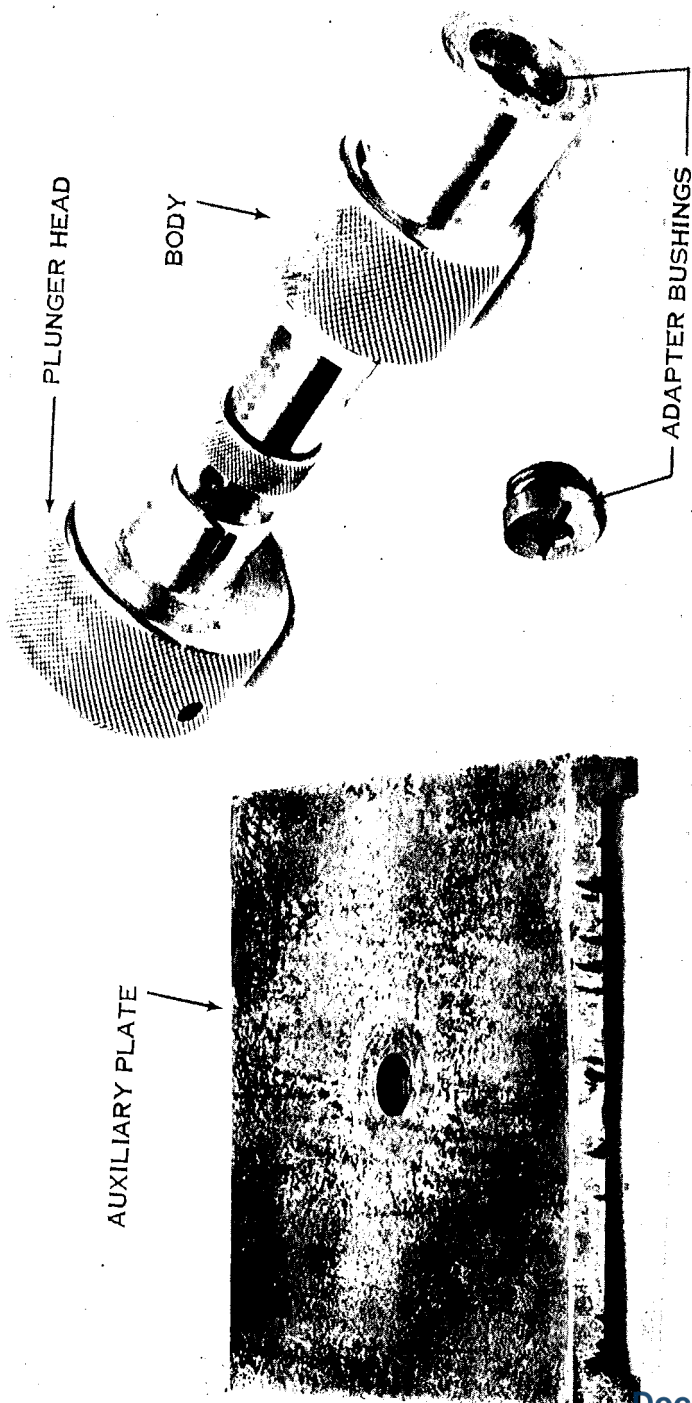


Fig. 4-2—Hydraulic pull-tester with auxiliary equipment

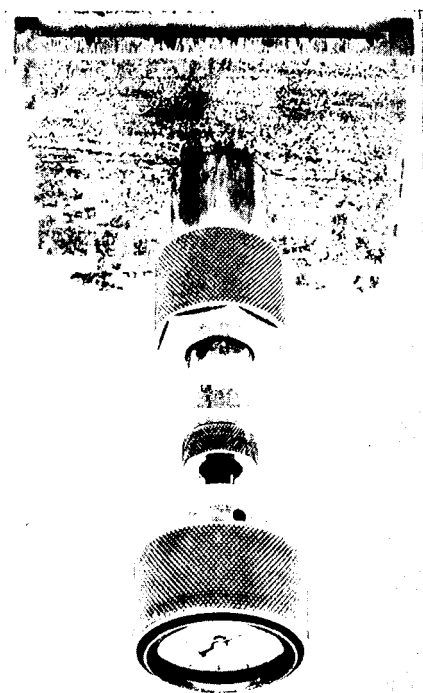


Fig. 4-3—Hydraulic pulltester assembled in normal working position

The testing consisted first of a visual inspection and a plier test to determine loose studs, and then each good stud was tested with a hydraulic pull-tester (Fig. 4-2 4-3). Fig. 4-2 shows the hydraulic pull-tester and its auxiliary equipment. Fig. 4-3 shows the device in its normal working position. The tester is operated by turning the knurled plunger head containing the pressure gage. The hydraulic cylinder in the body of the tester exerts a pull on a threaded hub into which threaded adapters, to fit various sizes of fasteners, may be screwed. The pressure gage in the plunger head indicates the hydraulic pressure in psi and the actual pull in pounds must be determined from a calibration curve. In order to simulate a dead-weight test as closely as possible, the 6-in. square plate with spacing lugs at the corners was employed to transfer the reaction to points outside the spall area. This auxiliary plate was used to insure that the upward force of the tester would be transmitted to the concrete outside of the spall area. The pull tester was made as a prototype for the manufacturer and was calibrated at the National Bureau of Standards. Where fasteners penetrated at a slight angle to the concrete surface the pull-out and holding loads reported were corrected on the

basis of the calibration curve (Fig. 4-4) derived from tests with the tapered bearing block in place. A 4150 lb limit was arbitrarily set because of the considerable manual effort required to operate the tester above 4150 lb.

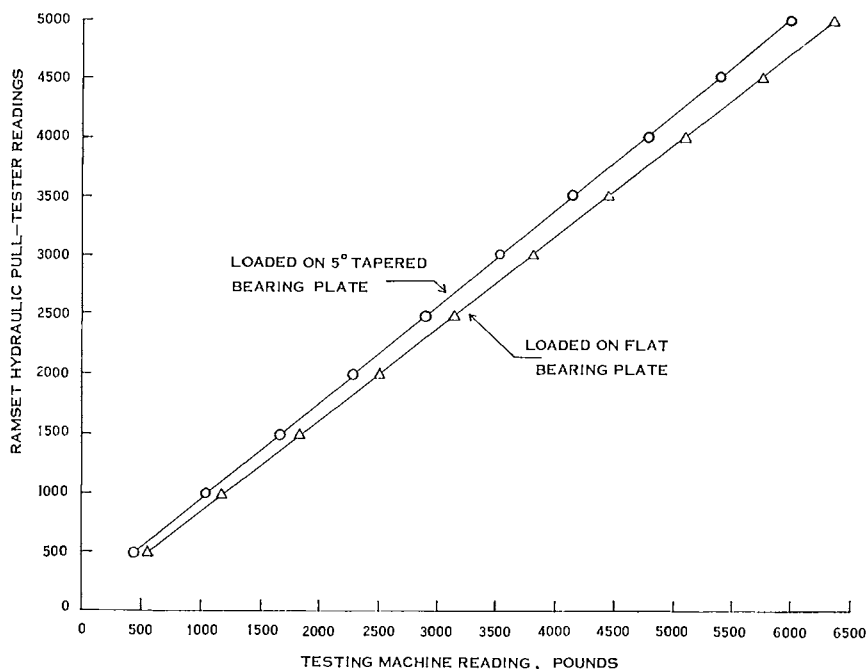


Fig. 4-4—Calibration curves for hydraulic pull-tester

TABLE 4-1 — ARCHIVES BUILDING TEST RESULT

Concrete:	Design strength — 2000 psi				
	Age, Approximately 30 years				
Location:	Subbasement				
Fastener:	Shank diameter — 0.25 in.				
	Shank length — 2.375 in.				
No.	Penetration	Visual	Plier	Pullout, lb	Spall in.
1	1.0	OK	OK	6000	2
2	1.0	OK	OK	6000	2
3	0.84	OK	OK	3700	5
4	0.84	OK	OK	4500	3
6	0.8	OK	OK	4750	5
7	0.685	OK	OK	3250	3
8	0.84	OK	F	—	—
9	0.84	OK	OK	4600	3
10	0.84	OK	OK	4750	3
11	0.84	OK	OK	*	4
12	1.0	OK	OK	*	3

It is noted in Tables 4-1, 4-2, 4-3, and 4-4 that regardless of the depth of penetration each stud formed a conical spall area measuring from 2 to 8 in. in the greatest dimension with depths varying from 1/2 to 1-in.

It is believed by the participants in these testing procedures that the age or strength of the concrete had little effect on the pull-out resistance or holding power of the studs and that the type of failures experienced were due largely to the type of aggregate used in the concrete.

The reliability of the fastener is dependent on the holding ability of the encompassing material. Test results shown in each of the tables demonstrated that the strength of the concrete has little effect on this holding ability. The hardness factor of the coarse aggregate appears to be one of the more important factors contributing to the success of the fastener.

TABLE 4-2 — APEX BUILDING TEST RESULT

Concrete:	Design strength — 2000 psi				
	Age, Approximately 27 years				
Location:	Basement, garage				
Fastener:	Shank diameter — 0.25 in.				
	Shank length — 2.375 in.				
No.	Penetration	Visual	Plier	Pullout, lb	Spall in.
1	0.84	OK	OK	*	3
2	0.84	OK	OK	3000	4
3	0.84	OK	OK	*	5
5	0.63	OK	OK	2150	3
6	0.24	OK	OK	*	4 1/2
7	0.84	OK	OK	*	2
8	0.74	OK	F	—	4
9	0.84	OK	OK	*	3
10	0.79	OK	OK	*	3
11	0.84	OK	OK	*	3
12	0.84	OK	OK	*	3

Recommended code requirements

Most safety codes requirements relative to the use of powder actuated fastening tools appear to be similar in content but are found lacking when compared to the recommendations of the Powder Actuated Tool Manufacturers Institute as contained in their Uniform Code.⁴

This PATMI publication should be seriously considered as the basic safety code wherever powder-driven fasteners are being used.

RECOMMENDATIONS

Acceptable applications

There exist many opinions as to the acceptable applications for powder-driven fasteners. The 1960 report¹ and the 1962-64 report² gives

TABLE 4-3 — FEDERAL OFFICE BUILDING NO. 1 TEST RESULT

Concrete:	Design strength — 2000 psi Age, approximately 25 years				
Location:	Basement				
Fastener:	Shank diameter — 0.25 in. Shank length — 1.625 in.				
No.	Penetration	Visual	Plier	Pullout lb	Spall in.
1	1.0	OK	OK	*	3
2	0.77	OK	OK	3000	4½
3	1.0	OK	OK	2650	7
4	1.0	OK	OK	1800	3
6	1.0	OK	OK	3150	6
7	1.0	OK	OK	*	4
10	1.0	OK	F	—	5
11	—	—	—	—	—
12	1.0	OK	OK	1750	5½
13	1.0	OK	OK	2050	7
14	—	—	—	—	—
15	1.0	OK	OK	*	4

the findings obtained from a survey of the practices and recommendations of some government and private agencies.

The consensus of these findings indicates that the acceptable applications for powder-driven fasteners are few and that their reliability in performance is doubtful.

Building Research Advisory Board — Federal Housing Administration Report to the FHA No. 4,³ provides some application data and criteria for the selection of studs. Most of this information is summarized in Table 4, of Reference 3. It can be noted from this tabulation that a

TABLE 4-4 — FEDERAL OFFICE BUILDING NO. 9 TEST RESULT

Concrete:	Design strength 3750 psi Age — Over 30 days				
Location:	Fifth floor				
Fastener:	Shank diameter — 0.25 in. Shank length — 1.625 in.				
No.	Penetration	Visual	Plier	Pullout lb	Spall in.
1	1.075	OK	OK	2900	2¾
2	1.0	OK	OK	2600	3½
3	1.075	OK	OK	2750	4½
5	1.0	OK	OK	2000	4
7	1.075	OK	OK	2650	4
34	1.0	OK	F	—	2½
9	1.075	OK	F	2000	5
10	0.54	OK	F	750	4
11	—	—	—	—	3
12	1.0	OK	OK	750	5½
13	1.075	OK	OK	1900	3