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AN OVERVIEW OF
POWER DRIVEN FASTENING FOR STEEL CONNECTIONS IN THE U.S. CONSTRUCTION INDUSTRY

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SUMMARY

Power driven fasteners provide a means for connecting steel elements, and are an alternative to the more conventional bolts, welds, and screws. The term "power driven" fastener includes both powder actuated and pneumatically driven fasteners. With these systems, a small high strength pin is driven into steel by an explosive charge (powder actuated) or by compressed air (pneumatically driven). Power driven fastening to steel is a well developed technology, with a strong basis in research and testing, and has been available in the U.S. for over 50 years. Yet, power driven fastening to steel is not well recognized in the U.S. and is not being used to its full potential.

This report documents a study providing an overview of power driven fastening to steel in the U.S. construction industry. This study was undertaken to achieve the following objectives: to develop a summary of current power driven fastener technology and to identify research and information needed to expand the use of power driven fasteners in the U.S. construction industry. These objectives were accomplished by collecting information on power driven fasteners; by identifying barriers to the use of power driven fasteners; and suggesting means of overcoming those barriers. This report is also intended to serve as a basis for future research on power driven fasteners by providing a summary of past research and identifying research needs.

An extensive literature search was conducted to identify and collect existing information on power driven fastening to steel. The results of this literature search are included in this report in the form of an annotated bibliography. This literature search revealed a very large body of research and testing on power driven fastening to steel. However, the vast majority of this technical database has not been disseminated in the U.S., and is largely inaccessible to the U.S. engineering and technical community.

Construction industry opinions regarding power driven fastening to steel were solicited through mail questionnaires, through telephone interviews, and through site visits. The purpose of this industry survey was to obtain information on perceptions and concerns about power driven fastening to steel. The results of the survey are summarized in this report.

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The primary current application of power driven fastening for steel in the U.S. is metal deck attachment in building floor and roof systems. There is still significant potential for increased use of power driven fastening in this area. Beyond metal deck attachment, there are currently a variety of other, largely nonstructural applications of power driven fastening for steel. These include the attachment of ductwork, sprinklers, pipe hangers, suspended ceiling hangers, metal studs, etc. There also appear to be a number of potential new applications of this fastening technology, which have not yet been fully explored.

Power driven fasteners for steel have the potential for significantly increased use in the U.S. construction industry. Some barriers need to be overcome, however, to reach the ultimate potential of these systems. Foremost among these is the need to address the information needs of the engineering and technical community in the U.S. The large body of research and testing available on power driven fastening to steel must be synthesized and disseminated in a form useful to engineers, educators, and researchers. The power driven fastener industry in the U.S. has put significant effort towards introducing and marketing their product to construction contractors. A similar effort, but with a more technical emphasis, is needed for engineers. An active and sustained program for disseminating technical information, directed towards the engineering and technical community in the U.S., provides the best opportunity for increasing the use of power driven fastening in currently recognized applications such as metal deck attachment, as well as stimulating the development of new applications. The final conclusions and recommendations of this study are summarized in Chapter 6 of this report.

ACKNOWLEDGMENTS

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INTRODUCTION

1.1 Background

Most steel buildings that are constructed today utilize metal decking for either their floor or roof systems. Metal decking can be used as form decking for pouring concrete floors, providing a composite or non-composite floor section. Metal decking can also be used for roof systems, serving as the roof itself or serving as a structural deck to be covered by a built up roof or architectural deck panels. Non-structural accessories such as electrical conduits, HVAC ducts, pipes or suspended ceilings are also utilized in almost every building. All these components must be connected to the structural framework.

The attachment of metal decking to the structural framework (steel beams, steel joists, cold-formed purlins, etc.) is typically accomplished by using puddle welds or self-drilling, self-tapping screws. Non-structural accessories are also often attached with screws. Other less common types of mechanical fasteners can also be used for these purposes.

One of the alternative types of mechanical fasteners that can be used in lieu of welds or screws are power driven fasteners. The name, power driven fasteners, has been adopted to incorporate both powder actuated and pneumatically driven fasteners. With these systems, a small high strength pin is driven by an explosive charge ("powder actuated") or by compressed air ("pneumatically driven") into concrete, steel or other materials. Powder actuated systems, an example of which is shown in Figure 1.1, are the most common form of power driven fastening systems. In the United States, power driven fasteners have been widely used for connections made to concrete but have received much less exposure for connections made to steel. Power driven systems for fastening to steel have been available since about the 1940's, and are well recognized in Europe. Power driven fastening into steel is much less widely known in the United States, and the

Figure 1.1 Typical powder actuated fastening system. (photo courtesy of Hilti)

U.S. construction industry still has many concerns about the safety and reliability of these fasteners for connections to steel.

1.2 Objectives of Study

This study was undertaken to achieve the following objectives: to develop a summary of current power driven fastener technology and to identify research and information needed to expand the use of power driven fasteners in the U.S. construction industry.

These objectives were accomplished by collecting information on power driven fasteners; by identifying barriers, which exist in the U.S., to the use of power driven fasteners; and suggesting means of overcoming those barriers. This project is also intended to serve as a basis for future research on power driven fasteners by providing a summary of past research and identifying research needs.

Extensive literature searches were conducted to identify and collect existing information on power driven fastening to steel. This included attempts to obtain information from studies sponsored by several major power driven tool manufacturers. Other literature was identified through use of the extensive computerized database searching capabilities of the University of Texas library system.

Construction industry opinions regarding power driven fastening to steel were solicited through mail questionnaires, through telephone interviews, and through site visits. The purpose of this industry survey was to obtain: information on barriers that exist or are perceived to exist, hindering expanded use of power driven fastening for steel in the U.S. for metal decking and other current applications; recommendations on research and information needs, and other actions required to overcome these barriers; and ideas of potential new applications for power driven fasteners.

Through this study it is hoped that U.S. construction professionals will become more aware of the potential of this fastening system and consider its use for future applications. It is also hoped that the manufacturers will become more aware of the needs of the construction industry.

CHAPTER 2

BACKGROUND ON POWER DRIVEN FASTENING TO STEEL

2.1 History

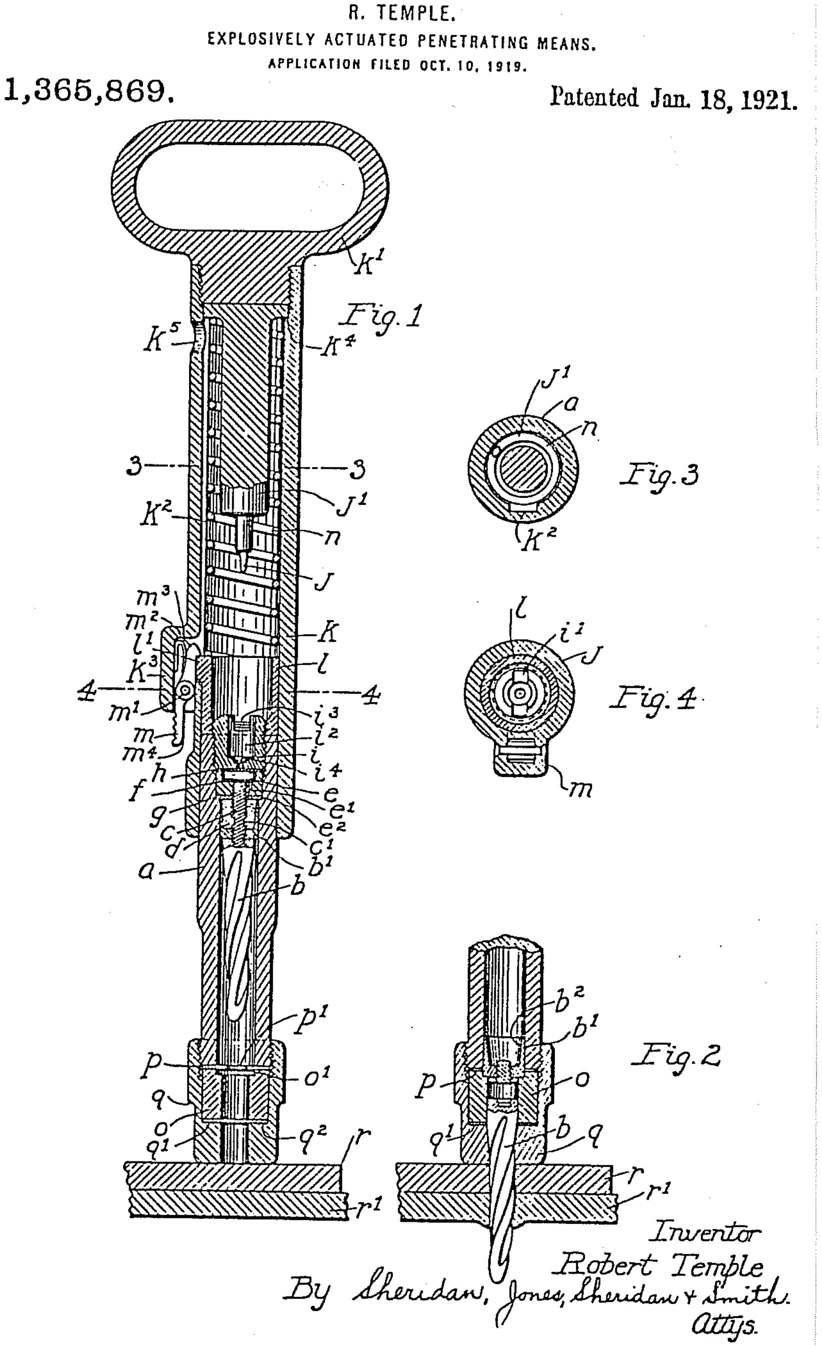
The history of power driven fasteners is not well documented; accounts vary between manufacturers. The history provided in this section was obtained from literature provided by two major manufacturers of power driven systems: Hilti (from unpublished reports) and by ITW Ramset/Redhead (from. Ref. 1). Each source pertains primarily to the particular manufacturer's history. The origin of power driven fastening systems is virtually the only undisputed portion of the history. This section will provide a general overview of the developments made during the past eighty years. Specific accomplishments will not be attributed to particular manufacturers, since the available literature sometimes provides conflicting historical accounts.

In the early 1900's an Englishman, by the name of Robert Temple, developed the first powder actuated nailing device. The original purpose of this device was to locate submarines during World War I. A diver could drive a nail into the hull of a submarine and run a line to a signal light on the surface, marking the sub's location. This system could also be used to try to save the lives of men trapped in disabled submarines. By firing a hollow nail through the ship's hull an air hose could be connected to the nail to pump fresh air into the submarine for both survival and buoyancy. A heavier version of this tool was used to patch holes in the hulls of ships by attaching new sheets of steel. Powder actuated tools are still used for this purpose today. Figure 2.1 shows a diver utilizing an underwater powder actuated tool in the 1950's.

Temple's original powder actuated tool, shown in Figure 2.2, was granted United States Patent Number 1365869 in January 1921. Temple patented a cattle stunner in 1926, which was based on his original patent. The cattle stunner was used to kill animals fast and painlessly. The tool did not utilize a projectile to accomplish this objective; instead,

Figure 2.1 Diver using an underwater powder actuated tool. (photo courtesy of ITW Ramset/Redhead).

it contained a captive piston and was the forerunner of the low velocity captive piston that is used today. Unfortunately for Temple, the potential of the captive piston system was not recognized at the time and Temple died in 1931 without seeing his invention prosper. Temple's efforts were carried on by his sons; they wanted to develop a tool for commercial use, particularly by the construction industry. The original tools were not used in the construction industry since they were bulky and heavy, weighing as much as eighty pounds.



R. TEMPLE.
EXPLOSIVELY ACTUATED PENETRATING MEANS.
APPLICATION FILED OCT. 10, 1919.

1,365,869. Patented Jan. 18, 1921.

Inventor
Robert Temple
By Sheridan, Jones, Sheridan + Smith.
Attys.

Figure 2.2 Original powder actuated tool patent.

A tool was developed in 1943, which weighed only half as much as the tools made thirty years previously, but was still inefficient for commercial adaptation. A typical high velocity tool from this period is shown in Figure 2.3. In 1947, a low caliber (.22) tool was introduced to the construction industry that weighed less than two pounds. This marked the beginning of the powder actuated tool market for construction purposes in the United States.

The early powder actuated tools were high velocity tools (high velocity and low velocity systems will be discussed in depth in section 2.5.1). This means that when the fastener leaves the muzzle it is capable of attaining velocities around 1500 feet per second. Fasteners driven at these speeds can be extremely dangerous if not installed properly. Recognizing the dangers inherent in high velocity systems, the industry developed hammer driven tools in the early 1950's. The hammer driven fastening system eliminated the dangers associated with using high velocity systems. Hammer driven systems utilize a guide tool and a common hammer.

Trigger operated powder actuated tools were also being introduced during this period. In the late 1950's the first low velocity piston assisted drive tools were manufactured. They had a maximum muzzle velocity of 280 feet per second. This greatly reduced the risks associated with high velocity tools and simultaneously provided a more efficient system than hammer driven tools. Further efforts to increase system efficiency resulted in the introduction of semiautomatic low velocity tools in the early 1970's.

In 1984, several manufacturers discontinued production of high velocity tools for commercial applications. The power driven fastener industry followed suit and high velocity tools disappeared from the commercial market in the period of 1984 to 1987. One reason that these tool systems were discontinued was the dangerous nature of high velocity tools and the associated liability . A small number of high velocity tools are still produced today, but only for highly specialized applications, for example military applications. In the commercial market, only low velocity tools are available.

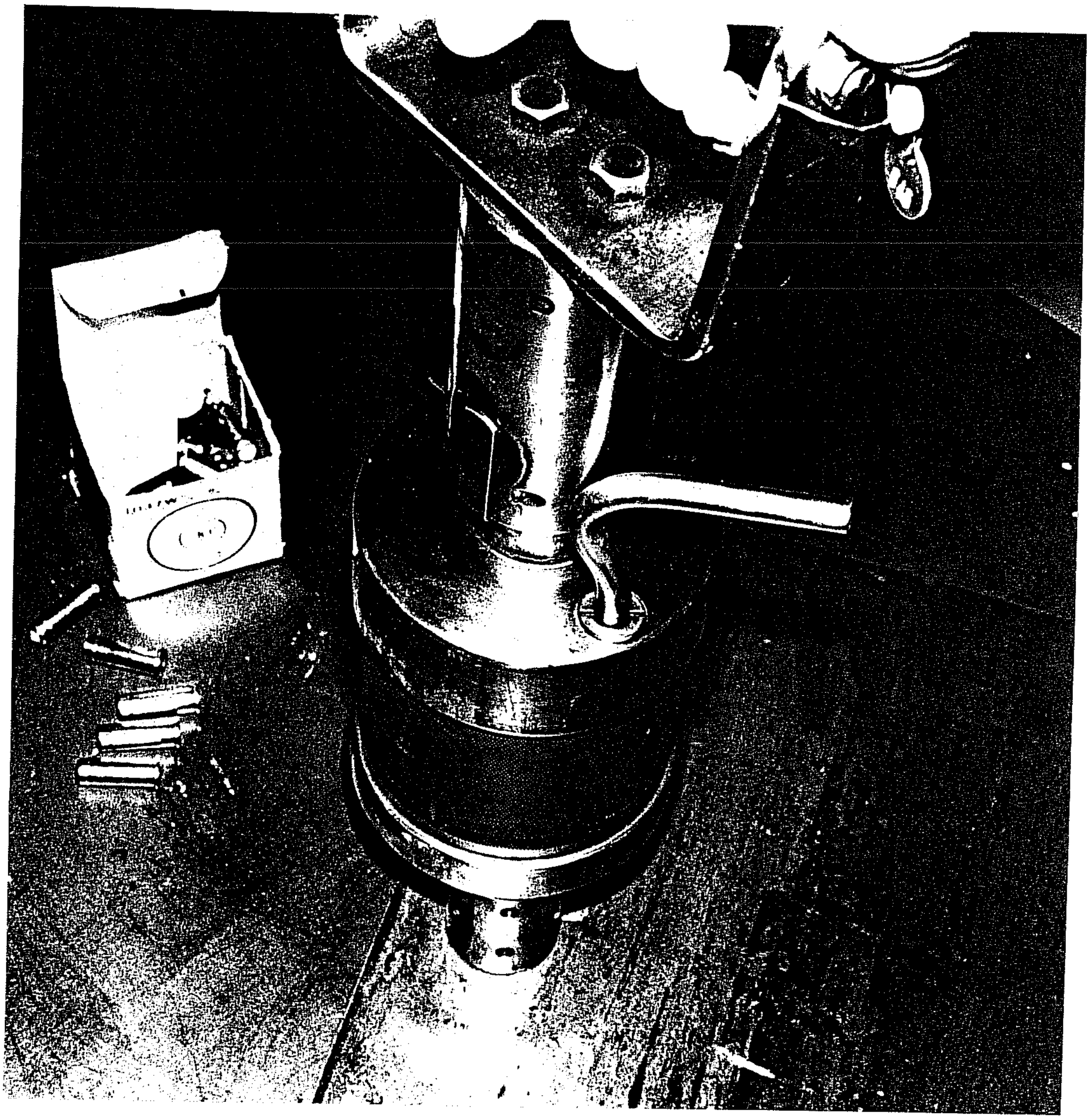


Figure 2.3 High velocity powder actuated tool from the 1940's. (photo courtesy of ITW Ramset/Redhead)

2.2 The Power Driven Fastening to Steel Process

This section will qualitatively describe the process of driving a fastener into steel. The information in this section was obtained from general unpublished information provided by power driven fastener manufacturers and from the Powder Actuated Tool Manufacturer's Institute (PATMI) Basic Training Manual[2].

In order to drive a power driven fastener into steel, it is reported that the fastener must be roughly four to five times harder than the base steel. The fasteners must also be sufficiently ductile so that they will not break during the driving process. Fasteners from different manufacturers vary but are typically specified to be made from AISI 1061 or 1062 modified steels, austempered to a Rockwell C hardness between 50 and 58. Typical fastener tensile strengths range from 240,000 to 285,000 psi and shear strengths are between 162,000 and 182,000 psi. Typical fastener shank diameters are in the range of 1/8" to 1/4", and the shanks can be smooth or knurled.

Manufacturers report that when a power driven fastener is driven into the base steel, the steel around the fastener shank is displaced. The displaced steel that flows around the fastener holds the fastener by friction, and if shank knurling is present, by mechanical interlock. During the driving process, heat is generated, producing some fusion of the base steel and the fastener, contributing to holding power. Thus, a power driven fastener is held in steel by a combination of friction, mechanical interlock, and by fusion. The available literature did not provide any detailed models for quantifying these components. Only qualitative descriptions were found.

For maximum fastener holding power, manufacturers recommend that the fastener point should penetrate the base steel. The fastener is held in place as the result of the pressure generated by the steel trying to conform to its original shape, as shown in Figure 2.4. If the fastener does not fully penetrate the base material some pressure from the steel will act against the fastener and try to push it out of the base material, thus reducing the holding capacity of the fastener, as shown in Figure 2.5. These figures are based on drawings obtained from unpublished reports.

Some fasteners can still be used for applications where they do not fully penetrate the base material, but the holding capacity will be reduced. Knurled fasteners are preferred when the fastener does not penetrate the base material, due to their better holding power. However, if a knurled fastener is driven a long distance through the steel, the knurling on the fastener may be stripped, reducing the capacity of the connection. Therefore, knurled fasteners typically possess short shank lengths.

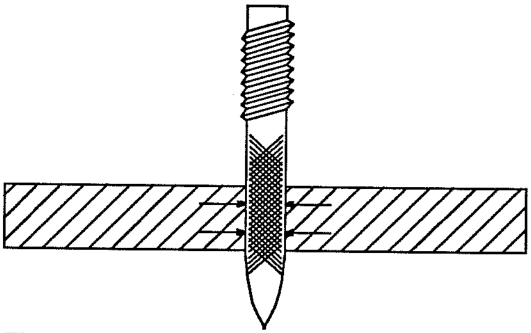


Figure 2.4 Forces acting on a fastener that fully penetrates the base material.

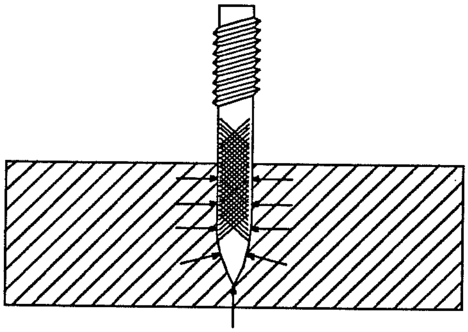


Figure 2.5 Forces acting on a fastener embedded in the base material.

2.3 Typical Current Applications

Power driven fasteners are currently used for a variety of structural and non-structural applications. When these fasteners are being driven through steel, their use is limited to connecting relatively thin elements to thicker structural members. In general, the maximum thickness of a steel element that can be connected is about 1/8" to 1/4", depending on the tool and fastener that are being used. The most common application of power driven fasteners is the connection of metal decking for use in floor and roof systems. This includes metal decking used for bare metal roofs, for built up roofs and for floors, as shown in Figures 2.6 and 2.7. In these applications, the fastener holds down the deck, and helps transfer diaphragm forces. The fasteners are therefore subject to a combination of tension and shear.

Figure 2.6 Metal floor decking. (photo courtesy of Hilti)

Figure 2.7 Metal floor decking with shear connectors for composite beams. (photo courtesy of Hilti)

Power driven fasteners have also been used for attaching non-structural components to steel members. These applications, shown in Figures 2.8 through 2.11, include the attachment of electrical conduit, HVAC duct, suspended ceilings, and pipe hangars. Power driven fasteners have also been used for grating installation, as shown in Figure 2.12. These figures are based on product

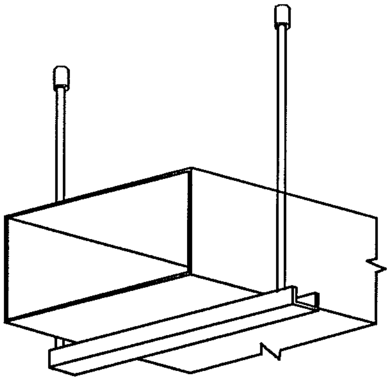


Figure 2.8 HVAC duct.

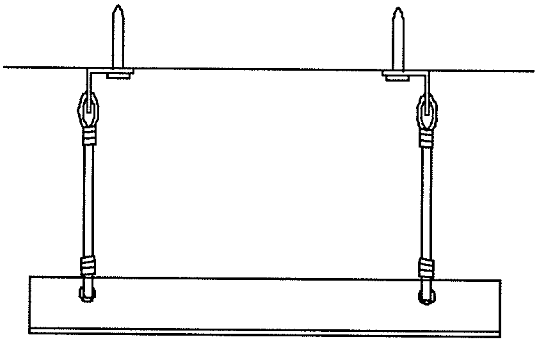


Figure 2.9 Suspended ceilings.

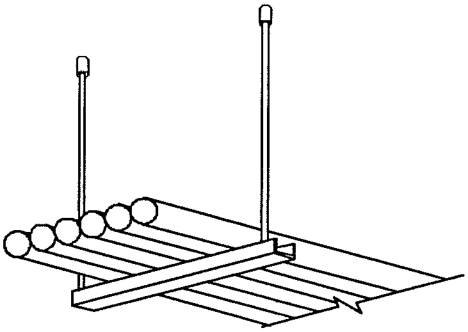


Figure 2.10 Conduit rack.

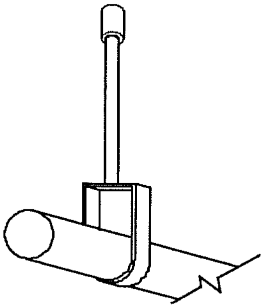


Figure 2.11 Sprinkler pipe.

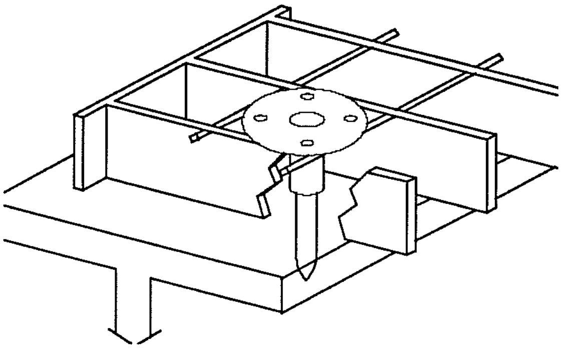


Figure 2.12 Grating installation.

literature provided by power fastener manufacturers. Power driven fasteners have also received some use for steel beam - concrete floor composite construction with the use of a cold-formed shear connector, as shown in Figures 2.12 and 2.13. For this application, the cold-formed shear connectors are attached to a steel beam with power driven fasteners, and used in lieu of the more conventional welded shear stud. Fastening wood to steel for various structural and non-structural applications can also be performed using power driven fasteners. Drywall track is another common component that is attached with power driven fasteners. Applications will be discussed further in section 5.3, which will discuss current applications as indicated by construction professionals and section 6.3, which will discuss some possible future applications.

2.4 Illustration of Tools and Fasteners

There are many different power driven tools, fasteners and accessories available from a number of manufacturers. The following sections provide an overview of some of the products that are available. These sections are not, however, intended to be an exhaustive inventory of all manufacturers' products.

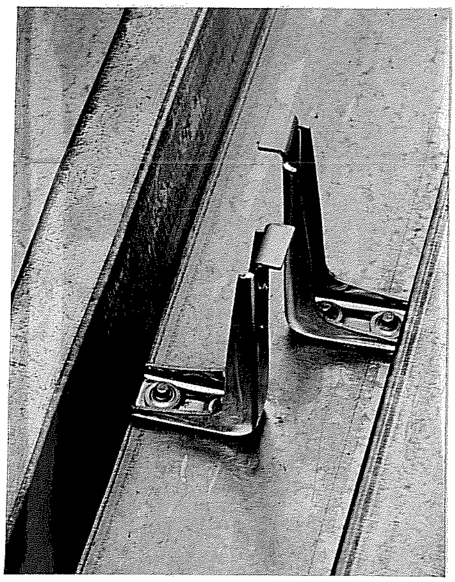


Figure 2.13 Typical cold-formed shear connector. (photo courtesy of Hilti)

2.4.1 Tools. There are three general categories of power driven fastener tools: powder actuated, pneumatically driven and hammer driven. The hammer driven tool reduces power driven fastening to its simplest form. These tools are not truly power driven fasteners, as discussed in this text, but the concept of driving the fastener is the same, although the power source is different.

Powder actuated tools take one of two forms: single shot or semiautomatic. Single

Figure 2.14 Single shot powder actuated tool. (photo courtesy of ITW Ramset/Redhead)

shot tools, an example of which is shown in Figure 2.14, can only drive one fastener at a time. After driving a fastener both the fastener and the power load must be reloaded. To increase system efficiency semiautomatic tools were developed. An example is shown in Figure 2.15. Semi-automatic tools utilize multiple power loads, in the form of either a strip or a disc (shown in section 2.4.3). However, not all semi-automatic tools utilize fastener magazines. For some systems a fastener must be loaded after each fastening operation, while others use magazines to load the fasteners.

Powder actuated tools can be either high velocity or low velocity tools (discussed further in section 2.5). High velocity tools (no longer commercially available) can fasten through thicker materials than low velocity tools, but are not as safe. The power level in most tools is varied by using different power loads (discussed in section 2.4.3). However, some powder actuated tools have an additional capability to vary the power level.

Figure 2.15 Semiautomatic powder actuated tool. (photo courtesy of ITW Ramset/Redhead)

Pneumatic tools are the last form of power driven tools. An example is shown in Figure 2.16. These tools utilize compressed air to drive the fasteners instead of powder charges. Whereas powder actuated tools require no external power source, pneumatic tools require an air compressor.

Different applications call for the use of different tools, as the thickness of the steel that can be penetrated with each tool varies. Typically, high velocity powder actuated tools can penetrate the thickest materials followed by low velocity powder actuated tools, pneumatic tools and hammer driven tools.

2.4.2 Fasteners. There is a wide range of fasteners available for power driven fastening for steel connections. There are threaded studs available for removable applications, fasteners specifically for metal decking applications, fasteners for attaching

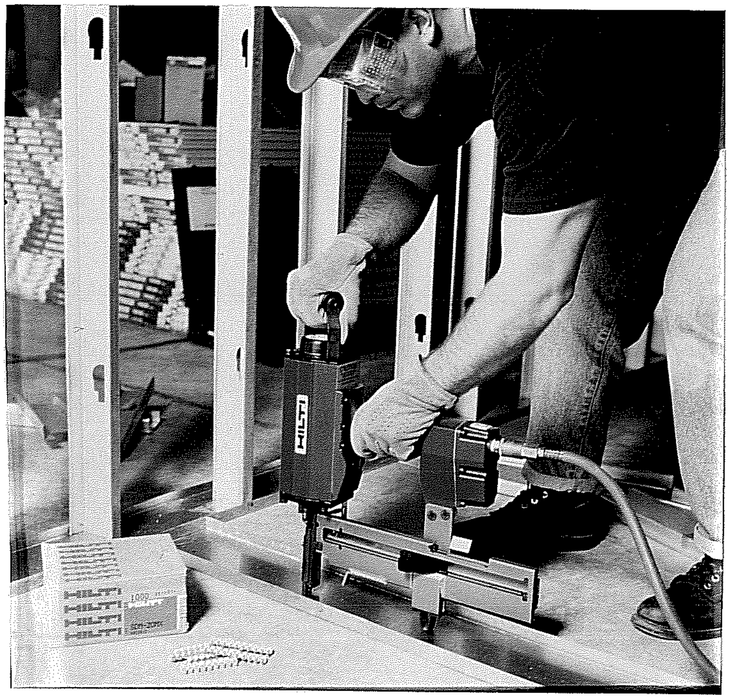


Figure 2.16 Pneumatically driven tool. (photo courtesy of Hilti)

wood members and many other types of fasteners. Some of the various fasteners are illustrated in Figure 2.17. An installed fastener is shown in Figure 2.18. There is no standardization of fasteners, and each manufacturer produces their own line of fasteners.

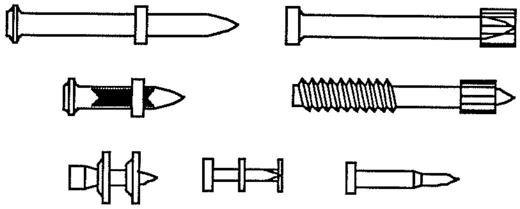


Figure 2.17 Typical power driven fasteners.

Despite the variety of the fasteners, most fasteners do contain some typical characteristics. In general, fasteners range in length from about 1/2" up to 3" long. Knurled fasteners are typically less than 1" in length. The range of shank diameters is from about 1/8" to 1/4". The most common diameters are in the .140", .170" and .205" ranges. Most fasteners generally are equipped with some form of a washer or hat. The washers and hats serve several purposes. They are used to properly guide the fastener within the tool,

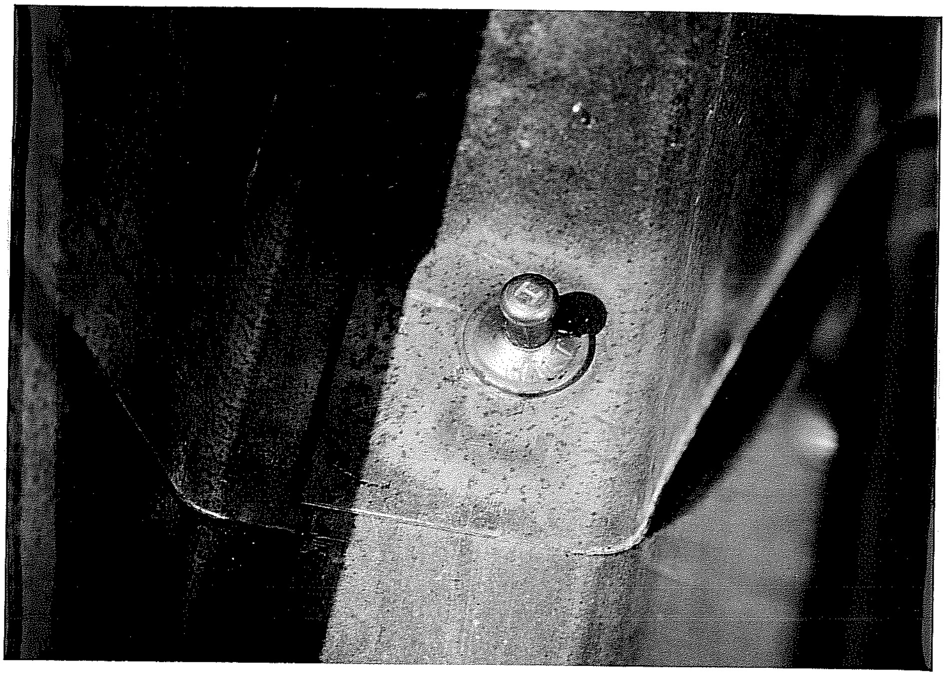


Figure 2.18 Typical installed power driven fastener. (photo courtesy of Hilti)

so that it will remain straight while being driven. They will also help to reduce the possibility of firing the fastener all the way through the material.

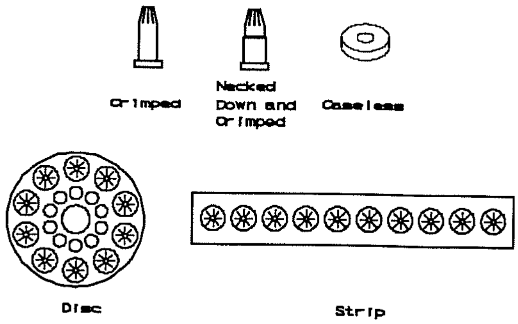


Figure 2.19 Various forms of power loads.

2.4.3 Power Loads. The most common forms of power loads, shown in Figure 2.19, are crimped cases and caseless. They can be used as single loads or enclosed in strips or discs for use in semiautomatic tools. There are twelve different power load levels available; they are differentiated by a system utilizing six load colors and two case colors, as shown in Table 2.1. The power levels have been established by the ANSI A10.3[3] safety

Table 2.1 Power load color identification.

Power Level	Case Color	Load Color
1	Brass	Gray
2	Brass	Brown
3	Brass	Green
4	Brass	Yellow
5	Brass	Red
6	Brass	Purple
7	Nickel	Gray
8	Nickel	Brown
9	Nickel	Green
10	Nickel	Yellow
11	Nickel	Red
12	Nickel	Purple

standards. The caseless loads are available in power levels one through six. Cased loads are available in all twelve power levels. However, powder actuated tools available for use today, typically, only use the first six power loads. Each individual tool has limitations on the power loads that can be used; many tools cannot use all the power loads. Power loads are also available in different caliber sizes. Typical caliber sizes are .22, .25 and .27.

Safe use of powder actuated tools requires selection of the proper power load. Choice of power loads is also important for obtaining a reliable connection. Manufacturers' literature recommend an operator initially try a fastener using the lowest power load available for the tool in use. If the fastener does not penetrate the material sufficiently, then the operator should proceed to the next higher power load. This trial and error process is repeated until proper embedment is achieved.

If the properties of the base material are unknown it is important to determine if power driven fasteners can be used. Manufacturers recommend performing a "center-punch test." One of the fasteners is used as a center-punch and struck with a hammer. If the fastener point becomes blunt, the material cracks or shatters or the fastener penetrates too easily, manufacturers recommend power driven fasteners not be used in the material. The material is presumably adequate if a small indentation in the material is visible and the fastener point is not blunt. This qualitative test has presumably been developed trough experience.

2.4.4 Specialty Fasteners and Accessories. There are a number of fasteners available for specialized applications such as conduit clips, ceiling clips, grating fasteners and insulation fasteners. Some of these are shown in Figures 2.20. The general form of the grating and insulation fasteners is shown in Figure 2.12. A threaded stud is fastened into the base material and the grating or insulation fastener is screwed onto the stud. A cold-formed shear connector, for use in composite construction, was shown in Figure 2.13.

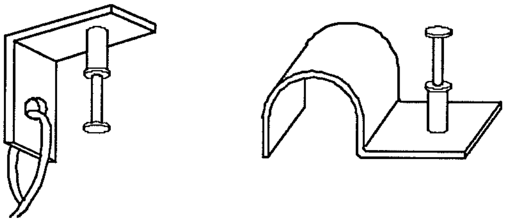


Figure 2.20 Typical ceiling hangar clip and conduit clip with pre-mounted fasteners.

There are also some accessories available for power driven tools. Some manufacturers provide pole tools for making overhead fastenings. There are also sealing caps available for some applications.

2.5 Safety

The safety of power driven fastening systems is one of the major concerns among the construction industry, as indicated by the surveys reported in sections 5.2 and 5.4. The Occupational Safety and Health Standards for the Construction Industry[4] (29 CFR Part 1926) outlines safety requirements for powder actuated tools. Item 12 of Section 1926.302 (e) requires that "Powder-actuated tools used by employees shall meet all other applicable requirements of American National Standards Institute, A10.3-1970, Safety Requirements for Explosive-Actuated Fastening Tools." The following sections will refer to the requirements contained in ANSI A10.3-1985, Powder Actuated Fastening Systems - Safety Requirements[3]. This document states the obligations of manufacturers, operators/instructors and employers. ANSI A10.3 is the basic standard by which all powder actuated fastening systems must conform. The remaining items addressed in the OSHA standard are also covered in ANSI A10.3. Unfortunately, no safety standards relating to pneumatically driven systems were found. However, many of the same principles can be applied to these tools. The following sections summarize key safety requirements related to powder actuated fastening.

2.5.1 High Velocity vs. Low Velocity Tools. A key issue related to the safety of powder actuated fastening is the use of low velocity versus high velocity tools. Formal definitions relating to powder actuated tools are provided by ANSI A10.3 as follows:

> **powder-actuated tool** (also known as tool). A tool that utilizes the expanding gases from a power load to drive a fastener. These tools can be divided into two types: direct acting and indirect acting; and three classes: low velocity, medium velocity, and high velocity.
>
> ***direct acting tool.*** A tool in which the expanding gas of the power load acts directly on the fastener to be driven.
>
> ***indirect acting tool.*** A tool in which the expanding gas of the power load acts on a captive piston, which in turn drives the fastener.
>
> **low-velocity tool.** A tool whose test velocity has been measured 10 times while utilizing the highest velocity combination of:
>
> (1) The lightest commercially available fastener designed for that specific tool

(2) The strongest commercially available power load that will properly chamber in the tool

(3) The piston designed for that tool and appropriate for that fastener

that will produce an average test velocity from the ten tests not in excess of 100 meters per second (m/s) (328 feet per second (ft/s)) with no single test having a velocity of over 108 m/s (354 ft/s).

medium-velocity tool. A tool whose test velocity has been measured 10 times while utilizing the highest velocity combination of:

(1) The lightest commercially available fastener designed for the tool

(2) The strongest commercially available power load that will properly chamber in the tool

(3) The piston designed for that tool and appropriate for that fastener

that will produce an average test velocity from 10 tests in excess of 100 m/s (328 ft/s) but not in excess of 150 m/s (492 ft/s), with no single test having a velocity of 160 m/s (525 ft/s).

high-velocity tool. A tool whose test velocity has been measured 10 times while utilizing the combination of:

(1) The lightest commercially available fastener designed for the tool

(2) The strongest commercially available power load that will properly chamber in the tool

that will produce an average velocity from the 10 tests in excess of 150 m/s (492 ft/s).

Most powder actuated tools are classified as high velocity or low velocity tools and, in general, high velocity tools are direct acting and low velocity tools are indirect acting. As discussed in section 2.1, high velocity tools dominated the industry in the early development of powder actuated systems. In the mid 1980's the high velocity systems were phased out and replaced by low velocity systems.

The ANSI test velocity requirements are important factors in determining the safety of power driven fastening systems. The free flight velocity of fasteners propelled by high velocity tools can be as high as 600 m/s (2000 ft/s). This extremely high velocity can result in dangerous conditions if the fastener ricochets, penetrates the base material, misses the base material entirely or if the tool is used in an unsafe manner.

Early in the development of power driven fastening systems safety was identified as an area of concern. Section 2.1 indicated that the first attempt to provide safer tools was the introduction of hammer driven tools. This did eliminate many safety concerns associated with power driven fastening systems. However, hammer driven fastening systems are inefficient for large projects. Further attempts to provide safer tools led to the development of the low velocity tool.

Figure 2.21 shows how a high velocity (direct acting) system propels the fastener, while Figure 2.22 shows the low velocity (indirect acting) system. These figures and the explanation used in this paragraph are based on unpublished reports obtained from tool manufacturers. Both systems can use the same power loads; therefore, the total energy possessed by both systems is the same. The kinetic energy principle ($E= mv^2$) states that energy is equal to one-half the mass multiplied by the square of the velocity. For direct acting systems, the total mass is equal to the mass of the fastener. Since the mass is small, the fastener travels at a high velocity. The indirect acting tool utilizes a captive piston to propel the fastener. The mass of the system is equal to the mass of the fastener plus the mass of the piston. Due to the larger mass, the velocity of the system must be reduced. Since the piston is captive it will reach a point where it cannot travel any further and the energy contained in the piston will be transmitted into the tool. The energy left in the fastener as it leaves the tool is only a small fraction of the total energy in the system; this energy is generally about 10 percent of the total energy since the ratio of the piston mass to the fastener mass is around 10:1. The piston and tool absorb most of the energy produced by the explosive cartridge.

Unpublished literature indicates that the velocity limit of 100 m/s (328 ft/s) for low velocity tools was established for safety reasons. The literature suggests that the risk of serious injury to an individual struck by a fired fastener is minimal for fastener velocities less than 100 m/s.

In the mid 1980's the commercial production of high velocity systems was abandoned by the power driven tool industry; today, only low velocity systems are available for commercial sale. Some older commercially available high velocity systems, however, are still being used today. Some manufacturer representatives have indicated that they still produce high velocity systems for special clients, such as oil companies, the military, and for repair of steel mill ladles.

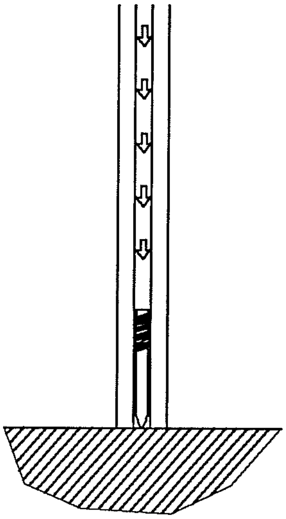


Figure 2.21 Direct acting system.

2.5.2 Safety Summary. The safe use of powder actuated fastening systems in the United States is governed by the regulations of OSHA. ANSI A10.3 provides extensive guidelines for the safe use of powder actuated tools. The Powder Actuated Tool Manufacturers' Institute Inc. (PATMI)[2] also provide guidelines that pertain to the safe use of these systems. These references include tool safety requirements ranging from safety mechanisms to displaying warning labels. They also provide recommendations on the limitations of operation. The purpose of the ANSI standard, which is required through OSHA, is to provide safety by establishing requirements on powder actuated tools.

ANSI requires that operators of powder actuated tools become certified. Operators must pass a written exam to prove their competence "with respect to (1) the requirements of this standard, (2) the powder-actuated fastening system, and (3) the specific details of operation and maintenance of the tools involved.[3]" Upon successful completion of the exam the operator will be issued a qualified operator's card that must be on his/her person when using the tool. PATMI has published a basic training manual that provides training that is common to all powder actuated systems. The individual manufacturers have their own training requirements besides those in the PATMI manual.

Discussions with manufacturer representatives have indicated that there is a significant emphasis on safety issues. Safety has been a large concern among the industry for several years. The key safety development of powder actuated fastening systems was the shift from high velocity to low velocity tools in the mid 1980's, discussed in section 2.5.1.

Safety statistics relating to the use of power driven fasteners were not found. OSHA representatives indicated that there were not any formal statistics on accidents involving powder actuated tools. The questionnaire results, discussed in Chapter 5, indicated that safety was a major concern among construction industry professionals, but no actual safety related problems reported. For further information on the safety of power driven fasteners refer to the safety section of the annotated bibliography in Appendix A.

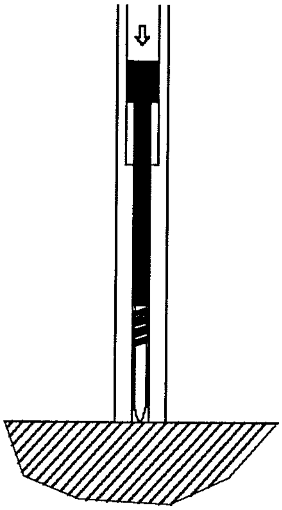


Figure 2.22 Indirect acting system.

CHAPTER 3

LITERATURE SEARCH

3.1 Overview

A primary objective of this study was to conduct a literature search and to develop a bibliography on power driven fastening to steel. Extensive literature searches were conducted to identify and collect existing information on power driven fastening to steel. This included attempts to obtain information from studies conducted by or sponsored by several major power driven tool manufacturers. Other literature was identified through use of computerized database searching.

3.2 Results

The results of the literature search are presented in the form of an annotated bibliography in Appendix A. This section will discuss how the literature search was conducted and what type of information was found in the search.

3.2.1 Computerized Database Searches. Extensive literature searches were performed through computerized databases available through the University of Texas library system. This search included the COMPENDEX database. This is an engineering index that contains a catalog of engineering related articles and books. The catalog includes article abstracts and a list of keywords used in the articles. Searches were conducted using keywords.

Initial investigations confirmed that power driven fasteners did not have a commonly used name. The term "power driven fasteners" was adopted for this study since it was the only name that encompassed both powder actuated and pneumatically driven systems. Among the names that were found in the literature are: power driven, explosive driven, powder driven, powder actuated, explosive actuated and pneumatically driven. Keyword searches were performed using these descriptors with the following subjects: fasteners, tools, fastenings and fastening systems. Searches were also performed to find related topics and more general categories such as fasteners/fastenings, metal decking, steel deck, roof deck, metal buildings, roof diaphragms, curtain walls, cladding and cold-formed construction. Literature on related topics was investigated by examining the abstracts, indexes and/or table of contents for applicable information.

3.2.2 Manufacturer Research and Test Reports. Preliminary investigations identified several different manufacturers of power driven tools and accessories. The three largest companies that market power driven systems in the United States, in alphabetical order, are: Hilti, Inc.; ITW Ramset/Red Head; and Pneutek, Inc. All three companies were requested to participate in the study by providing research studies performed by the individual organizations and any background information that was believed to be useful. Hilti and ITW Ramset/Red Head provided research reports and general information.

Through discussions with manufacturers, it was clear that each had research and test reports that were considered proprietary. No proprietary reports were included in the annotated bibliography. Many of the manufacturers research reports included in the bibliography, although not proprietary, are not easily available. In addition, language barriers also present some problems. A significant amount of the information obtained from the manufacturers was printed in German. Portions of these reports were translated to facilitate formulation of the bibliography as well as for informational purposes.

3.2.3 Range of Topics Covered by Bibliography. Although the amount of literature on power driven fasteners is limited, the information that is available encompasses a large range of topics. There is information on operator training, safety, the attachment of steel deck, steel shear diaphragms, cyclic loading, design information (Vulcraft Steel Floor and Roof Deck, SDI Diaphragm Design Manual), evaluations and approvals (Factory Mutual, ICBO), standard test methods (ASTM), composite behavior, tensile/shear/pull-over load testing, dynamic tensile loading, fatigue, sealing properties, temperature effects and corrosion under different weathering conditions.

Shear diaphragms are one of the few areas that have received a substantial amount of exposure in english language literature. This is one of the only areas of power driven fastening that includes published design aides. Equations have been developed for some of the fasteners for use in the design of shear diaphragms. This information is incorporated in the Steel Deck Institute's Diaphragm Design Manual[5].

The use of cold-formed shear connectors for composite beams appears to have received considerable attention in the literature. Many of the published journal articles as well as major portions of the research and test reports pertain to the use of the shear connectors. Nonetheless, cold formed shear connectors seem to be used by only a very small portion of the U.S. construction industry.

The largest portion of the research and test reports that were available for this study investigated the static strengths of the fasteners. Typical tests investigated the holding power under pure tension, pure shear and pull-over (decking) type loadings. Typically, most tests in the U.S. are performed on A36 steel and 33 ksi steel deck. Some tests were also performed to determine the dynamic and fatigue strengths of the fasteners. There are also reports investigating the corrosion and sealing properties of the fasteners. Much of the information from these reports is presented in Chapter 4.

There is not a wide variety of information available in terms of published articles and papers. The most common topics for published articles are: shear connectors, shear diaphragms, methods of fastening steel deck, general overviews of power driven fastening systems and safety.

There have been a several articles published on the safety issues involved with using power driven fasteners. These articles typically do not present the results of safety related studies or safety statistics. Rather, these articles provide general guidelines for the safe use of powder actuated tools. There are a several training guides available, and OSHA and ANSI standards outline the safety requirements imposed on the use of power driven fasteners.

The annotated bibliography is divided into nine sections to more easily accommodate the reader. Each category is arranged according to the year of publication. The nine sections are arranged as follows: journal articles/papers, university reports, general literature, safety, manufacturer literature, design aides, approvals, related literature and manufacturer product literature.

Some explanation is necessary for several of the sections. The safety, design aides, approvals and manufacturer product literature sections are self-explanatory. The journal articles/papers section includes research papers that were published in journals or conference proceedings. The general literature section contains textbooks, magazine articles, etc., pertaining to power driven fasteners that do not fall into one of the other categories. The manufacturer literature section contains Information obtained from the manufacturers including research and test reports and general information. The related literature section contains literature relating to applications pertaining to power driven fastening to steel. The material in this section does not necessarily contain pertinent information on power driven fastening; it may only be mentioned as an option within the text of the reference.

3.3 Observations and Comments

From the annotated bibliography in Appendix A, it is clear that the public domain literature in the U.S. (journals, trade magazines, conference proceedings, etc.) contains very little information on power fastening to steel. Of the few articles found, most are nontechnical in nature, dealing with general overviews of power fastening or with safety. Few research or technically oriented articles on power fastening to steel have been published in english language engineering literature.

The literature review revealed a great deal of research and testing information contained in unpublished manufacturer or testing laboratory reports. These reports, in general, are very difficult to obtain. From discussions with power fastener manufacturers, it also appears that there is a great deal of proprietary technical data that is not represented in Appendix A.

Overall, it appears there is a strong basis in research and testing for power fastening to steel. Certain aspects of fastener performance have been quite thoroughly investigated with extensive laboratory test programs. However, the vast majority of this technical database for power fastening to steel is largely inaccessible to the U.S. engineering community. The primary source of technical data on power fastening to steel for engineers in the U.S. in the very limited information provided in manufacturer's catalogs and brochures. Results of the industry survey described in Chapter 5 suggests that the lack of published technical data may be a significant barrier to increased acceptance of power fastening technology by the U.S. engineering community.

CHAPTER 4

FASTENER CAPABILITIES

4.1 Overview

This chapter is intended to provide an overview of the structural capabilities of power driven fasteners used for connections to steel. As discussed previously, there is very little public domain literature available on power driven fastening to steel. Most of the information used in this chapter comes from the testing and research reports provided by the manufacturers. Capabilities and limitations of the fasteners will be discussed as well as some strength trends in relation to variation of material properties. Some design comparisons will also be presented, particularly for diaphragm design. Much of the fastener test data discussed in this chapter is summarized in graphical form in Appendix B. This data is reproduced from manufacturer test reports in Appendix B, as the original reports are generally quite difficult to obtain.

4.2 Limitations of Power Driven Fastening to Steel

The following section identifies some of the limitations imposed upon power driven fastening systems for use in steel connections. These limitations are largely based on recommendations found in manufacturer's sales literature or are based on discussions with manufacturer's representatives.

4.2.1 Properly Driving Power Driven Fasteners. The correct power load must be chosen for driving the fasteners for both safety and reliability reasons. Overdriving and underdriving fasteners can result in a connection that will not have the holding capability that is expected. Determining if the fastener is properly driven is typically accomplished by a visual inspection. Adequate penetration can be determined by using a gage provided by some manufacturers. The gage typically shows an upper and lower limit for the height of the fastener head above the fastened material. There are some problems with these inspection techniques which will be discussed in section 5.4.2.

4.2.2 Spacing and Edge Distances. The PATMI Basic Training Manual[2] provides recommended limitations for fastener spacing and edge distances as shown in Tables 4.1 and 4.2, respectively. These recommendations appear to be based upon judgement; to the knowledge of the authors there are no research reports that have investigated the spacing or edge distance criteria. Most manufacturers also provide minimum fastener spacings and edge distances in their product literature.

Table 4.1 Recommended Minimum Fastener Spacing.

Fastener Shank Diameter	Minimum Spacing
1/8" through 5/32"	1"
11/64" through 3/16"	1-1/8"
7/32" through 1/4"	1-1/2"

Table 4.2 Recommended Minimum Edge Distance.

Fastener Shank Diameter	Fastener to Edge of Steel
1/8" through 5/32"	1/4" (low velocity tools only)
1/8" through 1/4"	1/2"

4.2.3 Maximum and Minimum Material Thickness. Power driven fastening systems also have limitations on the thickness of both the attached material and the base material. For the material to be fastened there is not a minimum material thickness. The maximum thickness of the attached material will depend on several variables, such as: the power load level, the type of fastener being used and the material being connected. Based on discussions with the manufacturers, the maximum thickness of the attached steel is in the range of 1/8" to 1/4", when using low velocity tools. When the attached material is a soft material such as wood the only limitation on the thickness of the material is that the fastener must be long enough to penetrate the base material.

The recommended minimum base steel thickness as indicated by PATMI[2] is shown in Table 4.3. The maximum base steel thickness depends on the type of fastener that is used. According to the manufacturers, when smooth shank fasteners are used, the fastener must fully penetrate the base material, otherwise substantially reduced holding values will be obtained. Some manufacturers indicate that knurled fasteners do not have a limitation on the maximum thickness of the base material.

Table 4.3 Recommended Minimum Base Steel Thickness.

Fastener Shank Diameter	Minimum Thickness
1/8"	1/8"
5/32" through 3/16"	3/16"
7/32" through 1/4"	1/4"

4.3 Fastener Strength

Power driven fasteners can be used in a wide variety of applications. Both tensile and shear loads are common occurrences for applications that use power driven fasteners. Tensile and shear loads are a common occurrence in metal decking applications due to wind uplift and diaphragm shear loads. Fasteners are also subject to tensile forces in applications such as the attachment of suspended ceilings, pipe hangars, HVAC duct, etc. This section will discuss the capacities of power driven fasteners under tension and shear loading. Failure modes and test methods will also be discussed briefly.

4.3.1 Failure Modes. The typical failure modes associated with tensile loads are shown in Figure 4.1. Power driven fasteners subjected to tensile loads can fail as the result of: a tensile failure of the fastener (fastener tensile failure), the fastener pulling out of the

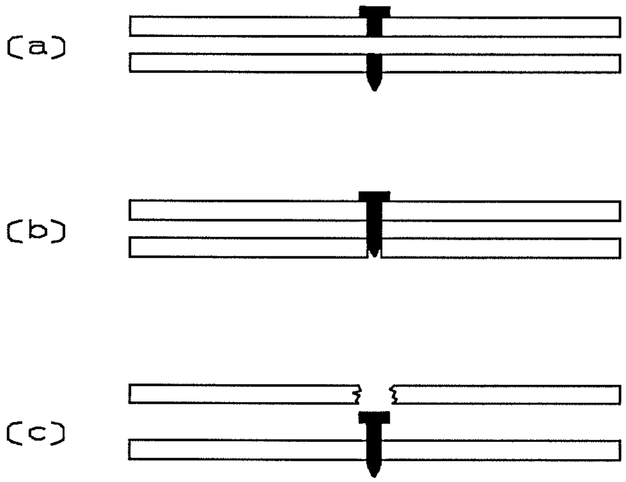


Figure 4.1 Tensile failure modes: (a) fastener tensile failure, (b) pull-out failure and (c) pull-over failure.

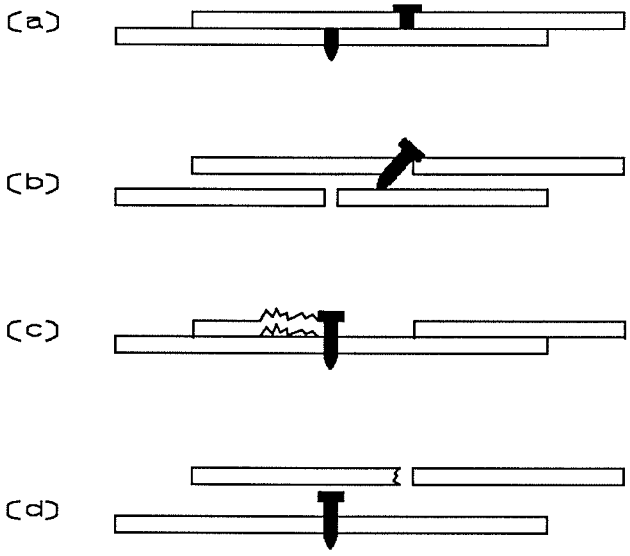


Figure 4.2 Shear failure modes: (a) fastener shear failure, (b) pull-out failure, (c) bearing failure and (d) pull-over failure.

base material (pull-out failure) or the attached material pulling over the fastener (pull-over failure). Pull-over failure, as used in this report, is intended to cover situations where the attached material fails, but the fastener remains intact. This includes the case where the attached material deforms and pulls out from under the head of the fastener and the case where the material tears around the head of the fastener.

Power driven fasteners subject to shear loads can fail as the result of: a shear failure of the fastener (fastener shear failure), the fastener pulling out from the base material (pull-out failure), bearing failure or pull-over failure of the attached material. Shear failure modes are shown in Figure 4.2.

Research has shown that power driven fasteners subject to tensile loads typically exhibit pull-out or pull-over failures. Shear failure modes will typically be pull-over or pull-out failures. Fastener tensile and fastener shear failures occur much less frequently.

4.3.2 Test Methods. The test methods employed for power driven fasteners are similar to those used for conventional fasteners. Standard test methods for powder actuated fasteners are provided by the American Society for Testing and Materials in ASTM Designation E1190-87: Standard Test Methods for Strength of Powder-Actuated Fasteners Installed in Structural Members[6]. Since the major use of power driven fasteners is the installation of metal decking, test methods for cold-formed construction may also be used extensively. Typical shear and tension tests for cold-formed members are shown in Figures 4.3 and 4.4.

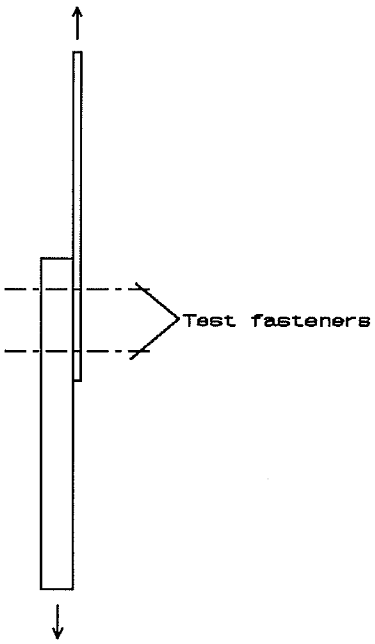


Figure 4.3 Typical cold-formed shear test.

4.3.3 Previous Test Results. One of the results of the literature survey was the acquisition of a significant number of test reports. This section is not intended to cover all test data that is

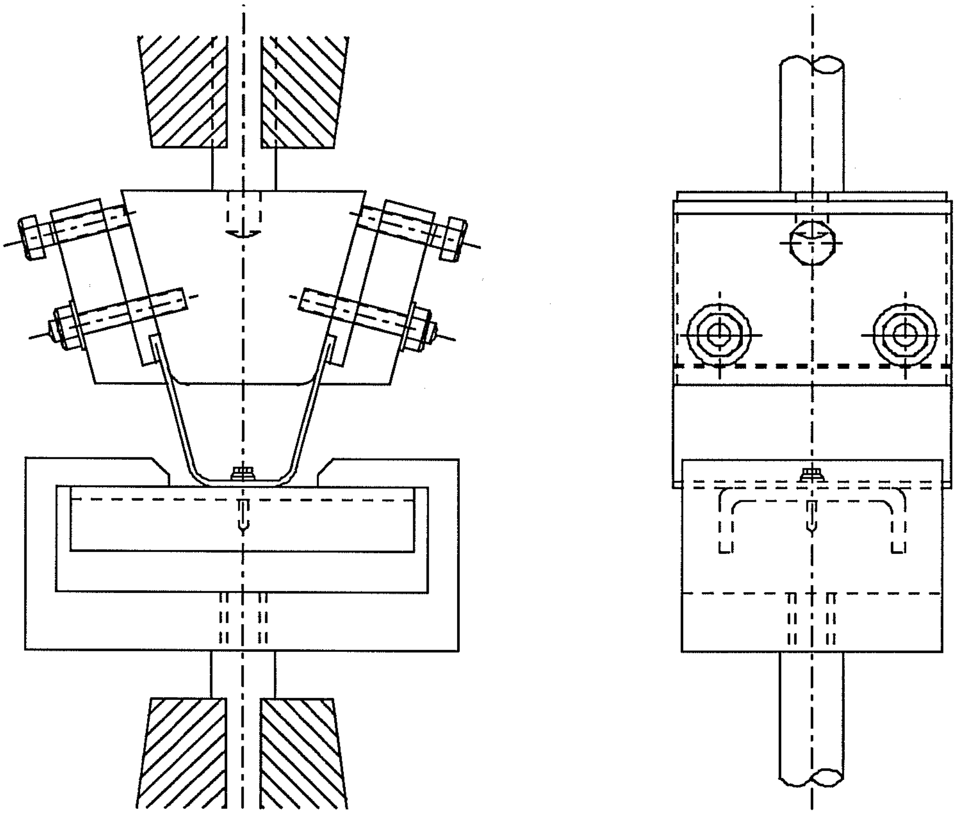


Figure 4.4 Typical tension test fixture for cold-formed members.

available on power driven fasteners, but will present representative or typical results from some of the reports. Data from test reports acquired from Hilti and ITW Ramset/Redhead are presented in tabular form and plots showing the distribution of load values are included in Appendix B. Hilti provided a large number of reports for tests that were conducted in Europe; this data will not be presented in this section. The appendix does not contain plots for tests that contained less than ten samples.

One of the largest problems associated with the test data that was available for this project was a lack of adequate documentation. Many test reports lacked adequate information on material properties. Variation of material properties may affect the holding capabilities of the fasteners. In many test reports, the base material was identified as ASTM A36. However, no data was supplied on the actual mechanical or chemical properties of the steel. This is significant, since steels with a very wide range of yield strength, tensile strength, toughness, hardness, and chemical composition satisfy the ASTM A36 specification. Further, reports in many cases did not provide basic data such as: depth of fastener penetration into base metal, fastener failure mode, details of test setup, load-deformation plots, and loading rates. Due to the lack of information, reliable interpretations of some of the results could not be made. The lack of careful and thorough documentation of testing programs unfortunately limits the usefulness of much of the existing data.

ITW Ramset/Redhead provided test reports on the shear and tension values of fasteners driven with both hammer driven and powder actuated tools. A variety of fasteners were used and the base material thickness ranged from 1/8" to 1/4" for hammer driven fasteners and 1/4" to 3/4" for powder actuated fasteners. The information provided in the Ramset reports was not very extensive. There was no information provided on failure modes or depth of penetration. Therefore, it is impossible to definitively establish the reasons behind any of the trends exhibited in their data, although some possible explanations are provided. For the hammer driven fasteners, twenty five test specimens were used for each fastening situation for both shear and tension. For the powder actuated fasteners, twenty five test specimens were used for the tension test configurations and only five test specimens were used for the shear tests.

The tension test results from the hammer driven fasteners are shown in Table 4.4. The results show that the connection strength increases with an increase in the shank diameter or an increase in base material thickness. These are expected trends assuming the fastener fully penetrates the base material in all cases.

Table 4.5 shows the shear test results obtained from the hammer driven fasteners. When the fastener diameter is held constant some interesting results are obtained. For the .156" and .140" diameter fasteners, the shear strength is highest for the 3/16" thick base material and the values for the 1/4" base material are substantially less than the values for the 1/8" material. For the .125" diameter fastener the highest strength occurs in the 1/8" thick base material and decreases as the base material thickness increases.

Table 4.4 Tension test values for a variety of Ramset hammer driven fasteners.

Fastener Diameter	Base Material Thickness	Average Tension Load (pounds)	Standard Deviation (pounds)	Maximum Tension Load (pounds)	Minimum Tension Load (pounds)
.156" Smooth	1/4"	2538	513	3325	900
	3/16"	1838	236	2250	1250
	1/8"	1190	288	1775	600
.140" Smooth	1/4"	1738	449	2300	750
	3/16"	1326	380	1800	600
	1/8"	834	294	1350	300
.125" Smooth	1/4"	1120	400	1800	400
	3/16"	1060	239	1500	500
	1/8"	784	119	1000	550

Interesting results are also seen when the base material thickness is held constant. For the 3/16" thick base material, the strength values increase with an increase in shank diameter. This is the normal trend associated with power driven fasteners for steel connections. However, for both the 1/4" and 1/8" thick base material the values obtained from the .140" diameter are slightly less than the values obtained from the .125" diameter fasteners.

The reasons for the unusual trends discussed above are not known. A possible explanation for the unusual trends is the consistency of the hammer driven power source. Since hammer driven fasteners are installed using a common hammer, there may be large variations in the amount of energy used to drive the fastener, which could result in variations in the depth of penetration. The depth of penetration has a large affect on the strength of the connection as discussed in section 2.2. If the fastener point becomes embedded in the base material the strength will begin to decrease. Due to the lack of information provided, no fastener lengths or penetration depths, the specific cause of this trend cannot be determined. The consistency of the power source could also explain the

Table 4.5 Shear test values for a variety of Ramset hammer driven fasteners.

Fastener Diameter	Base Material Thickness	Average Shear Load (pounds)	Standard Deviation (pounds)	Maximum Shear Load (pounds)	Minimum Shear Load (pounds)
.156" Smooth	1/4"	2392	763	4000	1000
	3/16"	3786	508	4750	3000
	1/8"	3278	295	3750	2500
.140" Smooth	1/4"	1098	380	2075	650
	3/16"	2792	598	3900	1400
	1/8"	2357	433	3250	1500
.125" Smooth	1/4"	1123	368	2100	475
	3/16"	1823	526	2800	1100
	1/8"	2396	166	2800	2150

large range of strength values for each test combination as shown in both tables.

Table 4.6 shows the shear test results obtained from a variety of Ramset power driven fasteners. Examination of the test results shows that as the shank diameter increases the strength gradually increases, by several hundred pounds with each increment, until the shank diameter reaches 1/4" which is accompanied by an increase in strength of three or four thousand pounds. The test results also show that the strength of the 1/4" diameter fastener in the 3/8" base material is slightly less than the same fastener in the 1/4" base material. Once again the reason for these trends cannot be determined due to the lack of information.

The similar strength values for the 1/4" fastener in both 1/4" and 3/8" material may be the result of the fastener tip becoming embedded in the 3/8" base material, resulting in a decrease in strength, or the shear strength of the fastener may have been reached. If the shear strength of the fastener is reached an increase in the base material thickness will not increase the strength of the connection. This case is unlikely however, as the result of the very high strength of the fastener. In addition, if the shear strength of the fastener

Table 4.6 Shear test values for a variety of Ramset power driven fasteners.

Fastener Diameter	Base Material Thickness	Average Shear Load (pounds)	Standard Deviation (pounds)	Maximum Shear Load (pounds)	Minimum Shear Load (pounds)
1/4" Smooth	3/8"	8974	221	9160	8710
	1/4"	9020	161	9250	8860
7/32" Smooth	3/8"	5966	211	6220	5680
	1/4"	5246	235	5620	5020
3/16" Smooth	1/4"	4762	85	4840	4660
11/64" Smooth	1/4"	4396	70	4480	4290
5/32" Smooth	1/4"	3538	59	3630	3480
9/64" Smooth	1/4"	2962	69	3000	2840

Table 4.7 Tension values for Ramset 9/64" diameter power driven fasteners.

Fastener Diameter	Base Material Thickness	Average Tension Load (pounds)	Standard Deviation (pounds)	Maximum Tension Load (pounds)	Minimum Tension Load (pounds)
9/64" Knurled	3/8"	3700	403	4400	2700
	1/4"	3068	417	3900	2100
9/64" Smooth	1/4"	1984	423	3100	1500

Table 4.8 Tension values for Ramset 7/32" diameter power driven fasteners.

Fastener Diameter	Base Material Thickness	Average Tension Load (pounds)	Standard Deviation (pounds)	Maximum Tension Load (pounds)	Minimum Tension Load (pounds)
7/32" Knurled	1/2"	5736	926	7600	4000
	3/8"	5912	714	7600	4600
	1/4"	4324	824	6300	2000
7/32" Smooth	1/2"	6028	479	7000	4800
	3/8"	4304	399	5000	3600
	1/4"	2928	354	3700	2200

Table 4.9 Tension values for Ramset 1/4" diameter power driven fasteners.

Fastener Diameter	Base Material Thickness	Average Tension Load (pounds)	Standard Deviation (pounds)	Maximum Tension Load (pounds)	Minimum Tension Load (pounds)
1/4" Knurled	3/4"	9924	233	10000+	9000
	1/2"	9188	817	10000	7000
	3/8"	7696	792	8600	5800
	1/4"	6164	536	6900	5000
1/4" Smooth	3/4"	7048	1357	9000	4500
	1/2"	5288	1355	7900	3000
	3/8"	4540	759	6400	3400
	1/4"	3108	596	4400	2000

was reached, the 7/32" fastener would also exhibit this trend since it has a smaller diameter. The values shown for the 7/32" fastener do not appear to conform to this trend since the values for the different base material thicknesses are not similar.

The results of Ramset's tension tests involving power driven fasteners are shown in Tables 4.7 through 4.12. A variety of fasteners were tested including both knurled and smooth shank fasteners. It should be noted that the maximum load that could be measured with the test apparatus was 10,000 pounds. It is for this reason that the maximum value for the 1/4" knurled fastener in 3/4" base material has a plus sign behind the strength value. In this test, twenty-two of the twenty-five test specimens reached the 10,000 pound load. Examination of the results shows the benefits of knurled fastener shanks. There are thirteen test combinations in which the effects of knurling can be examined. In eleven of these combinations, the average tension values of the knurled fasteners were between 1000 and 4000 pounds greater than their smooth shank counterparts. One of the remaining test combinations, the 5/32" diameter fastener in 1/2" steel, showed a 300 pound strength increase due to the knurling. The remaining test combination, the 7/32" diameter fastener in 1/2" steel, showed a decrease in strength of about 300 pounds, when knurling was present. The reasons for the strength trends shown in these two test combinations cannot be determined but it might be reasonable to assume that there were some adverse testing conditions which affected these two tests. The depth of penetration or some other factors may have adversely affected the strength of these connections. No fastener lengths were provided so the depth of penetration cannot be determined. Based on the other results it is fairly evident that knurling provides a substantial strength increase.

Most test combinations exhibit expected behavior for variation of base material thickness. All test combinations, with the exception of the 5/32" and 7/32" knurled fasteners and the 11/64" fastener, showed an increase in strength with an increase in base material thickness. For the three exceptions, the strength obtained with the 3/8" base material was slightly higher than the values obtained with the 1/2" base material. This information could further verify that there was a problem with the results of the 1/2" material for the two knurled fasteners as discussed previously. This trend could also be the result of the depth of penetration of the fastener which is unknown.

Table 4.10 Tension values for Ramset 5/32" diameter power driven fasteners.

Fastener Diameter	Base Material Thickness	Average Tension Load (pounds)	Standard Deviation (pounds)	Maximum Tension Load (pounds)	Minimum Tension Load (pounds)
5/32" Knurled	1/2"	3572	279	4100	3000
	3/8"	4212	201	4500	3800
	1/4"	3512	380	4200	2500
5/32" Smooth	1/2"	3292	470	3900	2300
	3/8"	2556	585	3600	1700
	1/4"	2264	417	2800	1500

Table 4.11 Tension values for Ramset 3/16" diameter power driven fasteners.

Fastener Diameter	Base Material Thickness	Average Tension Load (pounds)	Standard Deviation (pounds)	Maximum Tension Load (pounds)	Minimum Tension Load (pounds)
3/16" Knurled	3/8"	5144	473	5700	3900
	1/4"	3704	454	4300	2600
3/16" Smooth	1/2"	3660	572	4800	2500
	3/8"	3184	438	4100	2500
	1/4"	2483	342	3000	1600

Table 4.12 Tension values for Ramset 11/64" diameter power driven fasteners.

Fastener Diameter	Base Material Thickness	Average Tension Load (pounds)	Standard Deviation (pounds)	Maximum Tension Load (pounds)	Minimum Tension Load (pounds)
11/64" Smooth	1/2"	2616	693	4200	1600
	3/8"	2832	422	3400	1900
	1/4"	1556	370	2200	1000

The knurled fasteners show expected trends for fastener diameter variation. The strength increases with an increase in shank diameter for all material thicknesses except the 3/4" base material which was only used for the 1/4" diameter fastener. Smooth shank fasteners installed in 3/8" base material show an increase in strength with increasing shank diameter. For 1/4" and 1/2" base material, the strength values of smooth shank fasteners do not follow a specific pattern, but vary in random fashion.

A common trend among all the test results is the significant amount of variation between the maximum and minimum strengths for each test combination. The shear test results tend to have slightly less strength variation than the tension tests. Due to the lack of information, the reason for this trend cannot be determined. It could be due to variation in material properties or depth of penetration.

Hilti provided a large amount of test data for inclusion in this report. Not all of this data is presented in this section. Representative data are presented to illustrate trends. The information provided by Hilti's test reports was also limited. There was some information provided on the material properties. However, this information was relatively incomplete. All of the base material was identified as ASTM A36 steel. However, actual measured mechanical and chemical properties were not reported. Hilti typically used ten test specimens for each testing situation. However, some of their shear tests utilized only two or three test specimens, as indicated later.

The standoff, the height of the fastener head above the material, was indicated in most of the Hilti test data. It was assumed that all of the tests had adequate penetration depths as there was no information provided indicating a lack of penetration.

Tables 4.13 and 4.14 show the tension and shear test results for Hilti's EW6 (.145" shank diameter) and EW10 (.205" shank diameter) threaded studs, respectively. Hilti fastener designations beginning with an E indicate knurled fasteners. The values in both tables show a trend that is typical among the test results. For most fasteners, the strengths associated with an increase in material thickness will exhibit a trend in which the strength will gradually increase and then decrease slightly as the fastener point begins to become embedded in the base material. This trend will be discussed further in section 4.4.2. The

Table 4.13 Tension test values for Hilti EW6 and EW10 threaded studs.

Fastener Diameter	Base Material Thickness	Average Tension Load (pounds)	Standard Deviation (pounds)	Maximum Tension Load (pounds)	Minimum Tension Load (pounds)
.145" Knurled (EW6-20-12-D12)	3/16"	2454	244	2790	2030
	1/4"	2757	165	3115	2550
	3/8"	2766	189	3132	2570
	1/2"	2707	280	3138	2212
.205" Knurled (EW10-30-15-P10)	3/16"	2002	402	2500	1100
	1/4"	5092	255	5626	4814
	3/8"	5750	312	6100	5116
	1/2"	4459	516	5246	3364

Table 4.14 Shear test values for Hilti EW6 and EW10 threaded studs.

Fastener Diameter	Base Material Thickness	Average Shear Load (pounds)	Standard Deviation (pounds)	Maximum Shear Load (pounds)	Minimum Shear Load (pounds)
.145" Knurled (EW6-20-12-D12)	3/16"	2701	260	2905	2005
	1/4"	3403	115	3630	3225
	3/8"	3312	89	3480	3220
	1/2"	3202	174	3590	2935
.205" Knurled (EW10-30-15-P10)	3/16"	3751	413	4185	2870
	1/4"	7492	454	8065	6635
	3/8"	7704	436	8180	6850
	1/2"	5512	1046	7005	4020

shank lengths for the EW6 and EW10 fasteners are 1/2" and 5/8", respectively. Therefore, it is reasonable to assume that for the 1/2" fastener the point will begin to become embedded in the base material as the thickness approaches 1/2". However, the 5/8" fastener should penetrate the base material in all of the tests. Therefore, the reason for the strength decrease in the 1/2" material is unknown. Note also the fairly low values obtained for the EW10 fastener in 3/16" material under both tension and shear loading in comparison to the other strength values for that fastener.

Table 4.15 Tension test values for Hilti EDS and DS series fasteners.

Fastener Diameter	Base Material Thickness	Average Tension Load (pounds)	Standard Deviation (pounds)	Maximum Tension Load (pounds)	Minimum Tension Load (pounds)
.177" Knurled (EDS 22 P10)	3/16"	1648	216	1930	1385
	1/4"	3328	443	4130	2665
	3/8"	3989	271	4245	3420
	1/2"	5144	680	6215	3740
.177" Smooth (DS 27 P10)	3/16"	1970	211	2280	1580
	1/4"	3096	242	3575	2745
	3/8"	3874	593	4590	3005
	1/2"	2792	778	3900	1495
.177" Smooth (DS 52 P10)	3/16"	2394	192	2625	2010
	1/4"	3100	940	4000	810
	3/8"	4576	569	5430	3435
	1/2"	3674	1442	5130	1310

The Hilti EDS and DS fastener series (.177" shank diameter) test results are shown in Tables 4.15 and 4.16. For these fasteners the number following the series name indicates the shank length in millimeters (i.e., DS 27 P10 has a shank length of 27 mm). The results from the EDS fastener are an exception to the typical strength trend associated with increasing base material thickness. For the situations tested, the strength does not reach a point where it drops off. The EDS fastener has a shank length of 7/8" so

Table 4.16 Shear test values for Hilti EDS and DS series fasteners.

Fastener Diameter	Base Material Thickness	Average Shear Load (pounds)	Standard Deviation (pounds)	Maximum Shear Load (pounds)	Minimum Shear Load (pounds)
.177" Knurled (EDS 22 P10)	3/16"	3314	359	3780	2795
	1/4"	4666	206	5130	4445
	3/8"	4848	85	4945	4665
	1/2"	4986	189	5455	4025
.177" Smooth (DS 27 P10)	3/16"	3986	376	4440	3090
	1/4"	4400	264	4685	3915
	3/8"	4028	235	4420	3495
	1/2"	4464	238	4795	4095
.177" Smooth (DS 52 P10)	3/16"	4032	660	4450	2210
	1/4"	3116	432	3865	2425
	3/8"	3912	360	4520	3420
	1/2"	4060	315	4610	3555

it is reasonable to assume that the point does not become embedded in the base material. The DS fasteners have long shank lengths, greater than 1" long. These fasteners are smooth shank fasteners and are typically used for attaching wood members. The reason for the decrease in strength at higher base material thickness is probably the point becoming slightly embedded in the base material.

Some unusual results are shown in the shear test values for the DS fasteners. The strength values do not follow the typical trends for variation of base material thickness discussed previously. The reason for this trend may be variation of the depth of penetration. For the DS 27 P10 in 3/8" base material, all the fasteners exhibited pull-out failures. For the other three base material thicknesses, there was a mix of pull-out and shear failures. The fasteners in the 3/8" material appear to have had less penetration depth than the other tests and, therefore, resulted in a lower strength value than expected.

Table 4.17 Tension test values for Hilti DN fasteners.

Fastener Diameter	Base Material Thickness	Average Tension Load (pounds)	Standard Deviation (pounds)	Maximum Tension Load (pounds)	Minimum Tension Load (pounds)
.145" Smooth (DN 19 P8)	3/16"	1091	74	1180	930
	1/4"	1438	174	1625	1105
	3/8"	1360	141	1615	1160
	1/2"	1526	135	1690	1295
.145" Smooth (DN 27 P8)	3/16"	1800	131	2025	1665
	1/4"	2566	410	3040	1655
	3/8"	3447	555	4185	2410
	1/2"	3768	630	4335	2560
.145" Smooth (DN 52 P8)	3/16"	1835	294	2175	1440
	1/4"	2710	629	3230	1235

For the DS 52 P10 in 3/16" material, the fasteners exhibited pull-out or shear failures. For the other tests, the DS 52 P10 fasteners exhibited pull-out failures. It is interesting that some of the fasteners sheared in the 3/16" material but none of the fasteners sheared in the 1/4" through 1/2" material. The reason behind the unexpectedly large strength value for the 3/16" material cannot be determined from the information presented. The fasteners in the 3/16" material appear to have had a higher depth of penetration in the base material, thusgiving a higher strength than expected. These results demonstrate the effect that depth of penetration can have on the strength of connection.

Test results of the Hilti DN series fasteners (.145" shank diameter) are shown in Tables 4.17 and 4.18. As with the previous fasteners the number following the series name indicates the fastener shank length. The tension test strengths follow the typical strength trends with only one variation. The strength value for the DN 19 P8 fastener in 3/8" base material appears to be lower than expected. This test utilized a different power load than the other three tests. The strength may have been affected slightly by the use of the different power load, due to a variation in the depth of penetration.

Table 4.18 Shear test values for Hilti DN fasteners.

Fastener Diameter	Base Material Thickness	Average Shear Load (pounds)	Standard Deviation (pounds)	Maximum Shear Load (pounds)	Minimum Shear Load (pounds)
.145" Smooth (DN 19 P8)	3/16"	2256	441	2995	1565
	1/4"	2264	448	2770	1345
	3/8"	1846	226	2195	1545
	1/2"	1337	253	1725	1040
.145" Smooth (DN 27 P8)	3/16"	2448	344	2930	1835
	1/4"	3354	502	4720	2935
	3/8"	3275	138	3530	3100
	1/2"	3461	188	3705	3190
.145" Smooth (DN 52 P8)	3/16"	3179	183	3390	2885
	1/4"	2949	503	3640	1845

The shear test strengths of the DN fasteners exhibit several interesting trends. The strengths for the DN 19 P8 fastener actually decrease with an increase in base material thickness. Examination of the data showed that the depth of penetration appeared to decrease slightly with an increase in thickness for the given tests. However, the difference in depth of penetration does not seem to be significant enough to contribute to the trends indicated by the data. The reason for this strength trend cannot be determined. The results shown for the DN 27 P8 show a lower value for the 3/8" base material than expected. Examination of the test results showed that the fasteners in the 1/4", 3/8" and 1/2" base material exhibited shear failures. The limit of the fastener had been reached. The strength values for all three of these base material thicknesses are fairly close. Under pure shear of the fastener it would be expected that there would be some variation of strength values. It seems reasonable to assume that the deviation in the 3/8" material strength value is the result of this trend. This trend would also explain the values shown by the DN 52 P8 fastener since all of the tests for this fastener exhibited shear failures.

Table 4.19 Tension values for Hilti ENKK fasteners.

Fastener	Base Material Thickness	Average Tension Load (pounds)	Standard Deviation (pounds)	Maximum Tension Load (pounds)	Minimum Tension Load (pounds)
ENKK	3/8"	4324	278	4554	3840
	1/4"	4401	176	4580	4154
	3/16"	3266	362	3706	2374
	1/8"	2035	189	2306	1704

Table 4.20 Pull-over tension values for Hilti ENKK fasteners in 1/4" thick steel.

Fastener	Deck Thickness	Average Tension Load (pounds)	Standard Deviation (pounds)	Maximum Tension Load (pounds)	Minimum Tension Load (pounds)
ENKK	16 gauge	2024	72	2126	1812
	18 gauge	1745	63	1878	1684
	20 gauge	1394	46	1484	1322
	22 gauge	1384	67	1482	1272
	24 gauge	1131	70	1224	996
	26 gauge	474	74	572	396

The results of the tension tests of the Hilti ENKK fasteners are shown in Tables 4.19 and 4.20. The standard tension tests show the trends previously discussed for variation of material thickness. In addition, the range of strength values is fairly small. The pull-over tension tests showed results that would be expected. The strength increases as the deck thickness increases. The interesting feature of these tests is the small variation of the test values.

Table 4.21 Shear values for Hilti ENKK fasteners.

Fastener	Base Material Thickness	Deck Thickness	Average Shear Strength (pounds)
ENKK	1/4"	16 gauge	2674
		18 gauge	2095
		20 gauge	1688
		22 gauge	1496
		24 gauge	1056
		26 gauge	1386
	3/16"	16 gauge	2594
		18 gauge	2149
		20 gauge	1684
		22 gauge	1504
		24 gauge	1034
		26 gauge	1252

Shear tests were also performed on the ENKK fasteners utilizing varying deck thicknesses. There were only three tests performed for each situation so only the average values will be presented in this report. It is worth noting that the range of strength values was very small, typically a few hundred pounds. Table 4.21 shows the results of these tests. The values for both the 1/4" and 3/16" base material are similar. This is due to the failure mode of the tests; failure is controlled by bearing and pull-over failures. All of the tests involved some type of sheet failure. The only abnormal values appear to be the values for the 24 gauge deck, which are lower than both the 22 and 26 gauge decks. The reason for this low strength is not known; the test results indicated that the sheets failed early.

Table 4.22 Pull-over tension values for Hilti ENP2 & 3 fasteners in 1/2" thick steel.

Fastener	Deck Thickness	Average Tension Load (pounds)	Standard Deviation (pounds)	Maximum Tension Load (pounds)	Minimum Tension Load (pounds)
ENP2-21-L15	16 gauge	2793	99	2942	2668
	18 gauge	2391	122	2598	2192
	20 gauge	1984	88	2112	1808
	22 gauge	1623	64	1746	1550
	24 gauge	1473	115	1614	1266
	26 gauge	1075	127	1250	780
ENP3-21-L15	16 gauge	2070	54	2188	1992
	18 gauge	1631	89	1776	1468
	20 gauge	1478	74	1600	1386
	22 gauge	1241	72	1356	1118
	24 gauge	1127	108	1358	1012
	26 gauge	1016	108	1180	830

Hilti ENP2 and ENP3 tension test results are shown in Tables 4.22 and 4.23. The trends shown in these tables are typical of those discussed previously in this section for the other fasteners. Once again the pull-over tension test values are very consistent.

Shear tests were performed on the ENP2 and ENP3 fasteners as well. All of the tests were run on 5/16" thick base material. Only two tests were run for each test situation, the results of which are shown in Table 4.24. As with the ENKK fasteners, the results are typical with the exception of the 24 gauge deck strength values. For some unknown reason these values are lower than the surrounding values. The test reports indicated that the sheets failed early. It is possible that there may have been some problems with the 24 gauge deck.

Tables 4.25 and 4.26 show the tension test results for the Hilti ESD fastener. The standard tension results are very consistent and do not exhibit any unusual characteristics.

Table 4.23 Tension values for Hilti ENP2 & 3 fasteners.

Fastener	Base Material Thickness	Average Tension Load (pounds)	Standard Deviation (pounds)	Maximum Tension Load (pounds)	Minimum Tension Load (pounds)
ENP2-21-L15	5/8"	3141	465	3740	2438
	1/2"	3593	583	4284	2748
	3/8"	3633	467	4532	3028
	1/4"	2623	269	2966	2232
ENP3-21-L15	5/8"	2797	600	3740	2000
	1/2"	3024	307	3716	2754
	3/8"	3117	645	3838	2118
	1/4"	3017	317	3600	2394

An interesting trend is shown by the pull-over tension test results since the strength does not increase with an increase in deck thickness. For the 26 and 24 gauge deck, all the tests exhibited pull-over failures. The 22 gauge deck exhibited a mix of pull-over and pull-out failures. The tests performed using 16 to 20 gauge deck all exhibited pull-out failures. The deck thickness controlled for the very thin deck materials but not for the thicker deck tests. For the thicker deck sections, the strength was limited by the strength of the connection between the fastener and the base material. The range of strengths for the pull-over tests are very consistent.

4.3.4 Comments. The results from the previous section show some of the capabilities of power driven fasteners for steel connections. The results show that power driven fasteners have substantial holding ability, but that the range of strengths can be fairly large for some fasteners. The pull-over tests provided the most consistent test results as the standard deviation was rarely over 100 pounds. The shear test results also tended to be more consistent than the tension test results. The ratio of the maximum to minimum

Table 4.24 Shear values for Hilti ENP2 and ENP3 fasteners.

Fastener	Deck Thickness	Average Shear Strength (pounds)
ENP2-21-L15	16 gauge	2973
	18 gauge	2158
	20 gauge	1790
	22 gauge	1562
	24 gauge	1062
	26 gauge	1471
ENP3-21-L15	16 gauge	2824
	18 gauge	2240
	20 gauge	1624
	22 gauge	1656
	24 gauge	1109
	26 gauge	1494

strength values is large in a high percentage of the tests. Most of the test data appeared to conform to several trends which were discussed in the previous section. Trends associated with material and fastener properties will be discussed in section 4.4.

Table 4.25 Tension values for Hilti ESD fasteners.

Fastener	Base Material Thickness	Average Tension Load (pounds)	Standard Deviation (pounds)	Maximum Tension Load (pounds)	Minimum Tension Load (pounds)
ESD 16 P8TH	3/8"	1504	316	2024	1086
	1/4"	1367	131	1656	1172
	3/16"	1191	70	1284	1070
	1/8"	947	167	1138	658

Table 4.26 Pull-over tension values for Hilti ESD fasteners in 1/4" thick steel.

Fastener	Deck Thickness	Average Tension Load (pounds)	Standard Deviation (pounds)	Maximum Tension Load (pounds)	Minimum Tension Load (pounds)
ESD-16-P8TH	16 gauge	1460	142	1628	1142
	18 gauge	1474	141	1734	1220
	20 gauge	1732	96	1918	1588
	22 gauge	1573	108	1770	1346
	24 gauge	1321	98	1452	1090
	26 gauge	1201	84	1304	1056

4.4 Variation of Base Material and Fastener Properties

The properties of both the base material and the fasteners will affect the strength of the connection. This section will discuss how variations in these properties affect the strength of power driven fasteners.

4.4.1 Base Material and Decking Strength. Material properties are an area that has not been well documented in the research data that is available. This is an area that should be investigated in the future. The power driven fastening process requires the fastener strengths to be much higher than the base material strengths. Therefore, it is reasonable that the strength of the base material can have a significant effect on the strength of the connection. Manufacturer literature typically provides only one allowable value for each connection combination. Only one strength value is provided because testing has typically only been performed on A36 steel in the United States. It is expected that the allowable connection values would be higher if higher strength base materials were used. It would be beneficial to determine the effect of higher strength materials.

For the attachment of metal decking, the base material strength will be of little consequence since the failure will generally occur in the deck material. The manufacturer allowable load values for metal decking applications are typically based on a decking yield stress of 33 ksi. Once again, it would be expected that higher material strengths would lead to increased connection strengths.

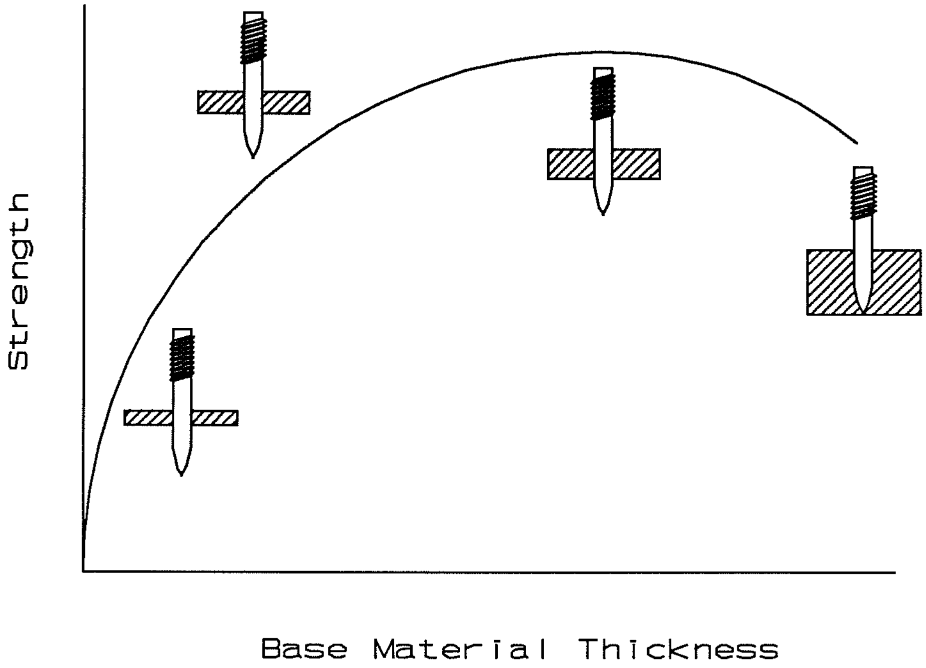


Figure 4.5 Typical base material thickness vs. strength relationship.

4.4.2 Base Material Thickness. The thickness of the base material has a significant impact on the strength of the connection. The strength of the connection is dependent on the amount of penetration in the base material and the shank diameter. Most fasteners will exhibit the general trend shown in Figure 4.5. This figure is based on some of the trends shown in the test reports and the actual shape of the curve may differ from the one presented.

As the base material thickness is increased, the connection strength will also increase, until a maximum load value is obtained. The maximum load value is attained when the total thickness (attached material plus base material) is equal to the shank length less the length of the fastener point. The strength decreases after the fastener point begins to become embedded in the base material. This decrease in strength is due to the forces acting on the fastener as described in section 2.2. Testing is normally stopped when the fastener is fully embedded within the base material. For thicknesses beyond this point, some manufacturers have suggested that the strength will remain constant. There was no data available to the authors on this issue.

4.4.3 Fastener Shank Diameter. The typical trend associated with shank diameters is that the larger the diameter the higher the strength. This trend is likely the result of the larger contact area associated with an increased fastener diameter.

The minimum base material thickness in conjunction with the shank diameter can also affect the strength of the connection. If the fastener shank diameter is larger than the base material thickness the strength of the connection may be abnormally low. Therefore, it is generally recommended that the shank diameter be less than the base material thickness. Specific recommendations for minimum thicknesses are presented in section 4.2.3.

4.4.4 Smooth vs. Knurled Shanks. The strengths obtained from knurled fasteners are expected to be higher than those obtained from smooth shank fasteners. The main reason for the increase in strength is due to the mechanical interlock provided by the knurling. The base steel tries to conform to its original shape after the fastener is driven. The steel moves back into the striations of the knurling, creating a better connection than smooth shank fasteners.

The benefit of knurled fasteners was clearly verified by the Ramset test data. It is harder to determine the affect of knurling in the Hilti test data. The values presented in section 4.3.3 are the actual test values and not the adjusted design values as determined by the manufacturer. One of the Hilti test reports indicated that "adjustments were made to combine load values for knurled and smooth shank fasteners of the same type since no clear performance difference was found."[7]

The power driven fastener industry has recognized the advantages of knurled shank fasteners by providing knurling. However, some manufacturers have neglected to add this benefit to their fastener design strength values. Some manufacturers provide fasteners that are available with knurled or smooth shanks. Typically, the smooth shank strength values are the basis for allowable load values for both smooth and knurled fasteners. If knurled shank fasteners are used, there is an additional safety factor built into the connection, the result of the unused strength increase.

The only limitation on the use of knurled shanks is the depth of penetration. If the fastener is allowed to penetrate too far the knurling will be stripped from the shank. Therefore, most knurled fasteners have short shank lengths, typically, one inch or less. Fasteners for fastening through wood or other soft materials generally have smooth shanks.

4.5 Factors of Safety

There are no standardized factors of safety for power driven fasteners. Currently the manufacturers recommend their own factors of safety, which are typically 10:1 or 5:1 for tension loads and 5:1 for shear loads. These safety factors appear to have been chosen somewhat arbitrarily by the manufacturers. ICBO requires different safety factors than some manufacturers, which can create confusion when using power driven fasteners.

Allowable design values for fasteners are typically established by dividing the average measured strength by the factor of safety. The factors of safety currently being used can be examined by considering the "strength ratio" for the data in section 4.3.3. Strength ratios as used in this section are defined as the ratio of the average connection strength to the minimum connection strength. These ratios are then compared with the safety factors.

Examination of the Ramset hammer driven fasteners show that the maximum strength ratios are about 3:1 for tension and 2.5:1 for shear. For Ramset's power driven fasteners the maximum strength ratios are about 2.2:1 for tension and 1.05:1 for shear. Ramset uses safety factors of 10:1 for tension and 5:1 for shear. All of the strength ratios easily fall within the limits of these safety factors.

For the Hilti fasteners the maximum strength ratios are about 3.9:1 for tension and 1.8:1 for shear. The 3.9:1 tension strength ratio was for the test in which the fastener diameter was larger than the base material thickness, outside the recommendations of PATMI[2]. The next highest tension strength ratio was 2.8:1. Hilti uses safety factors of 5:1 for both tension and shear values. All of the strength ratios fall within the limits of the safety factors.

The limited analysis above suggests that current factors of safety are quite conservative. Application of reliability theory to available test data could lead to more rational, and perhaps less conservative, factors of safety.

4.6 Diaphragm Design

Power driven fasteners are widely used for the connection of metal decking which often times serve as a roof or floor diaphragm. This section will examine the requirements for the use of power driven fasteners in diaphragm design. The second edition of the Steel Deck Institute Diaphragm Design Manual[5] (SDI DDM) provides guidelines for using some power driven fasteners. It contains connector strength and flexibility equations for the following fasteners: Ramset 26SD, Hilti ENP2-21-L15, Hilti ENP3-21-L15, and Hilti ENKK.

It is important to realize that power driven fasteners can only be used for connection of the decking to the structural framework. They can not be used as stitch fasteners (for side-lap connections). Screws or puddle welds are typically used for the side-lap connections when utilizing power driven fasteners for the frame connection.

Appendices V and VI of the SDI DDM contain tables indicating the design shear strengths for a variety of fasteners under different fastening situations. Tables 4.27 through 4.31 show the allowable shear values for 5/8" puddle welds, #12 screws and three different power driven fasteners for some selected fastening situations.

The tables indicate that when identical stitch fasteners are used, all the design shear values are similar. For the standard 1.5" deck and the 3DR deck, the Ramset and

Table 4.27 Sample design shear values for standard 1.5" deck.

Standard 1.5" Deck Fastener Pattern: 36/5 Design Thickness: .0295" Stitch Connectors per span: 4 Span: 6.5'		
Frame Fastening	Stitch Fastening	Design Shear, plf
5/8" Weld	Welds	415
5/8" Weld	#10 Screw (Buildex)	305
#12 Screw (Buildex)	#10 Screw (Buildex)	260
Ramset 26SD	#10 Screw (Buildex)	335
Hilti ENP2 & 3	#10 Screw (Buildex)	340
Pneutek Pins	#10 Screw (Buildex)	250

Table 4.28 Sample design shear values for standard 1.5" deck.

Standard 1.5" Deck Fastener Pattern: 36/3 Design Thickness: .0295" Stitch Connectors per span: 2 Span: 4'		
Frame Fastening	Stitch Fastening	Design Shear, plf
5/8" Weld	Welds	305
5/8" Weld	#10 Screw (Buildex)	260
#12 Screw (Buildex)	#10 Screw (Buildex)	200
Ramset 26SD	#10 Screw (Buildex)	280
Hilti ENP2 & 3	#10 Screw (Buildex)	280
Pneutek Pins	#10 Screw (Buildex)	185

Hilti power driven fasteners exhibit higher design shears than both the welds and screws while the Pneutek power driven fastener exhibits load values comparable to the screws. For the composite deck case, the design shear values for all five fasteners are practically

Table 4.29 Sample design shear values for standard 1.5" deck.

Standard 1.5" Deck Fastener Pattern: 30/3 Design Thickness: .0474" Stitch Connectors per span: 5 Span: 8'		
Frame Fastening	Stitch Fastening	Design Shear, plf
5/8" Weld	Welds	490
5/8" Weld	#10 Screw (Buildex)	355
#12 Screw (Buildex)	#10 Screw (Buildex)	320
Ramset 26SD	#10 Screw (Buildex)	380
Hilti ENP2 & 3	#10 Screw (Buildex)	385
Pneutek Pins	#10 Screw (Buildex)	325

Table 4.30 Sample design shear values for standard 3DR deck.

Standard 3DR Deck Fastener Pattern: 24/4 Design Thickness: .0358" Stitch Connectors per span: 9 Span: 10'		
Frame Fastening	Stitch Fastening	Design Shear, plf
5/8" Weld	Welds	530
5/8" Weld	#10 Screw (Buildex)	330
#12 Screw (Buildex)	#10 Screw (Buildex)	330
Ramset 26SD	#10 Screw (Buildex)	375
Hilti ENP2 & 3	#10 Screw (Buildex)	375
Pneutek Pins	#10 Screw (Buildex)	335

identical. These examples indicate that the allowable strength of an individual power driven fastener is comparable to that of a 5/8" puddle weld. Based on discussions with several power driven fastener manufacturers, it is clear that development of improved fasteners

Table 4.31 Sample design shear values for composite deck.

<table>
<tr><td colspan="3">Composite Deck/Structural (NW) Concrete
Fastener Pattern: 36/4
Design Thickness: .0598"
Stitch Connectors per span: 4
Span: 12'</td></tr>
<tr><th>Frame Fastening</th><th>Stitch Fastening</th><th>Design Shear, plf</th></tr>
<tr><td>5/8" Weld</td><td>Welds</td><td>1895</td></tr>
<tr><td>5/8" Weld</td><td>#10 Screw (Buildex)</td><td>1770</td></tr>
<tr><td>#12 Screw (Buildex)</td><td>#10 Screw (Buildex)</td><td>1720</td></tr>
<tr><td>Ramset 26SD</td><td>#10 Screw (Buildex)</td><td>1740</td></tr>
<tr><td>Hilti ENP2 & 3</td><td>#10 Screw (Buildex)</td><td>1745</td></tr>
<tr><td>Pneutek Pins</td><td>#10 Screw (Buildex)</td><td>1745</td></tr>
</table>

for metal decking attachment is an active area of research. New deck fasteners with improved strength values and improved speed of installation are expected.

4.7 Design Formulas for Tension and Shear According to Eurocode 3 Annex A

Formulas for determining the characteristic tension and shear strengths of metal deck attached with power driven fasteners in accordance with the Eurocode 3 Annex A are presented in Cold-Formed Steel in Tall Buildings[8]. The formulas and limitations are presented here only for reference purposes. To the knowledge of the author no design formulas are available in U.S. standards or codes. The tension strength formulas are as follows:

Pull-through, pull-over failures:

$F_p^* = d_w t f_u$ for static loads or

$F_p^* = 0.5 d_w t f_u$ for repeated loads with a spectrum similar to wind

Pull-out failures:

Characteristic pull-out strength > F_p^*

Tensile failure:

Not relevant in sheeting

subject to the following limitations:

$0.5 \text{ mm} < t < 1.5 \text{ mm}$

$t_1 > 6 \text{ mm}$

where:

d_w = diameter of washer or head of fastener
F_p^* = characteristic pull-over strength of a connection per fastener
f_u = specified ultimate tensile strength of steel sheet with thickness t
t = thickness of thinnest sheet
t_1 = thickness of thickest sheet (base material)

The shear strength formulas are as follows:

Hole bearing failures (including tilting):

$F_b^* = 3.2 f_u d_n t$

Failure of net section:

$F_n^* = A_n f_u$

Shear of Fastener:

Characteristic pull-out load due to shear shall exceed F_b^* by 50%

subject to the following limitations:

$e_1 \geq 4.5d_n$, $e_2 \geq 4.5d_n$

$u_2 \geq 4.5d_n$, $u_1 \geq 4.5d_n$

$3.7 \text{ mm} \leq d_n \leq 6.0 \text{ mm}$

$d_n = 3.7 \text{ mm} \rightarrow t_1 \geq 4 \text{ mm}$

$d_n = 4.5 \text{ mm} \rightarrow t_1 \geq 6 \text{ mm}$

$d_n = 5.2 \text{ mm} \rightarrow t_1 \geq 8 \text{ mm}$

where:

A_n = net cross-sectional area of plate material

d_n = nominal diameter of fastener

e_1 = edge distance in load direction

e_2 = center-to-center distance in load direction

F^*_b = characteristic shear strength of a connection per fastener, failure-mode hole bearing (including tilting and shear of section)

F^*_n = characteristic strength of a connection, failure-mode yield of net section

f_u = specified ultimate tensile strength of steel sheet with thickness t

t = thickness of thinnest sheet

t_1 = thickness of thickest sheet (base material)

u_1 = distance between edge and center of fastener perpendicular to load direction

u_2 = center-to-center spacing of fasteners perpendicular to load direction.

CHAPTER 5

CONSTRUCTION INDUSTRY OPINIONS

5.1 Overview

A principal objective of this project was to obtain information from the construction industry to determine their perceptions and concerns about power driven fastening to steel. Discussions were held, either by telephone or in-person, with architects, engineers, erectors, fabricators and deck manufacturers. In addition, three sets of questionnaires were mailed to the following groups: product sales personnel, steel erectors, and architects/engineers. The purpose of these discussions and the mail questionnaires was to obtain feedback from a cross-section of construction industry professionals on a variety of issues related to power fastening for steel.

The steel erector and architect/engineer questionnaires had similar purposes but were aimed at different audiences. The purpose of both questionnaires was to obtain opinions about the advantages, disadvantages and applications of this fastening technology. These questionnaires were also intended to provide information on the extent of power driven fastener use, reasons for not using power driven fasteners, fastener preferences, the role of specifications, potential for increased use, research needs and possible future applications for this fastening system.

The steel erector and engineer/architect questionnaires were sent to two hundred steel erection firms and two hundred architectural, engineering or A/E firms of varying sizes throughout the United States and had 32% and 24% positive returns, respectively. Among both the steel erector and engineer/architect questionnaires small portions of the questionnaires were returned because of incorrect addresses or because the firm did not use this or similar types of fastening systems in their line of work.

The sales personnel questionnaire was sent to fifty individuals working for Hilti, Inc. throughout the United States and there was a 68% return. The results of this questionnaire will only be used to provide additional information and the results will not be compared with those of the other two questionnaires even though some questions are the same.

The following sections present the results of the questionnaires and discussions. The questionnaires are included in Appendix C, for reference purposes.

5.2 Familiarity with Power Driven Fastening to Steel

An issue of concern is whether construction industry professionals are familiar with power driven fasteners for steel connections. Table 5.1 shows that most industry professionals have used this type of fastening system. However, one-fifth of the steel erectors and one-third of the architects/engineers have not used these systems. Through discussions with several industry professionals it was noted that most professionals were familiar with power driven fastening to steel but their knowledge was very limited. Despite their limited knowledge of power driven fasteners for steel connections most professionals are interested in the potential of the system.

Table 5.1 Has power driven fastening to steel been used on any of your projects?

Response	Steel Erectors	Architects/Engineers
Yes	81%	67%
No	19%	33%

5.2.1 Reasons for Not Using Power Driven Fasteners. There must be reasons why significant portions of the construction industry have not used power driven fasteners. Table 5.2 shows that very few respondents have never heard of power driven fastening for steel connections. However, numerous respondents indicate that they do not know enough about power driven fasteners to feel comfortable using them. This response may

Table 5.2 If power driven fasteners are not used
what is the reason behind this decision?

Response	Steel Erectors	Architects/Engineers
Never heard of power driven fasteners.	0%	13%
Don't know enough about power driven fasteners to feel comfortable using them.	25%	50%
Specifications prohibit their use.	25%	----
Safety concerns.	17%	31%
Other	42%	50%

be related to the almost complete lack of public domain literature on this subject in the United States, as noted in Chapter 3.

Reasons that were in the "other" category include: the systems are too slow, the tooling is unreliable, the cost is high in comparison to conventional methods, noise concerns in renovation work (when the building is occupied during renovation), the fastener is not strong enough to make the desired connection, the base steel is too thick to take a fastener, and there is no way to test their capability other than through destructive testing. These comments are related to some disadvantages of power driven fastening systems that will be discussed in section 5.4.2. Several respondents indicated that their field of practice does not include areas in which power driven fasteners for steel connections are used.

Safety concerns were noted prominently both in discussions with engineers and in the questionnaires. Many individuals felt that power driven systems, and powder actuated systems in particular, were unusually dangerous. None of the individuals reported personal knowledge of a serious accident involving power driven systems. Thus, concerns about safety appear to result from the perception of danger, rather than from actual experience with the systems. The perception that power driven systems are inherently unsafe appears to represent a significant barrier to increased use of these systems.

5.2.2 Role of Specifications. The role of specifications in the construction industry is a very important issue. The steel erector questionnaire showed that specifications played an important role in limiting the use of power driven fasteners. Therefore, the role of specifications was expanded upon in the architect/engineer questionnaire. Table 5.3 shows the format that most specifications take. It is surprising that 19% of the respondents indicated that the specifications specifically state that power driven fasteners may be used and only 14% of the specifications prohibit the use of power driven fasteners (4% specifically and 10% do not permit alternatives). About 85% of the specifications allow the use of power driven fasteners (either specifically or with proper approval).

Two-thirds of the specifications allow the use of power driven fasteners with proper approval. The process of approval may vary depending on location and the parties involved in the project but most of the approval processes follow the same general format.

Table 5.3 Our company's specifications:

Response	Architects/Engineers
Specifically state that PDF may be used.	19%
Specifically prohibit the use of PDF.	4%
Specify conventional fasteners (bolts, screws or welds) and do not permit alternatives.	10%
Specify conventional fasteners (bolts, screws or welds) but permit approved alternatives.	44%
Contain generalized statements saying that suitable fasteners shall be used.	21%

A request must be made by the contractor or subcontractor for approval by the structural engineer. This request must typically be accompanied by manufacturer engineering data or test evaluations by code agencies (BOCA, ICBO, UL, Factory Mutual, etc.). The engineer must then approve the alternative method of fastening.

This can be a lengthy and expensive process for contractors. Many contractors may use the fasteners that are already approved by the specification, which typically does not include power driven fasteners.

5.3 Current Applications

Typical current applications were discussed in section 2.3 and the questionnaire results verify this information, as shown in Table 5.4. The questionnaire results vary between participants. The steel erector and architect/engineer results show comparable results for the metal decking applications but large variations for the non-structural applications. This could be due to the fact that most of the steel erectors do not deal with non-structural installations, since they are performed by other subcontractors (i.e., plumbing, electrical, HVAC, etc.). The architect/engineer typically would have more interaction with the other subcontractors and would, therefore, see it used more for the non-structural applications than the steel erector would.

The largest uses of these fasteners are for metal decking applications, primarily for built-up roofs and form decking for composite floors. They are also used extensively for connecting non-structural elements such as pipes, HVAC ductwork, electrical conduit, hangars for suspended ceilings and siding. Besides the applications listed above several other applications were indicated, including the attachment of: metal grating for walkways, drywall track, wood (for various purposes), metal studs, light gage framing to the support structure, shear connectors in composite construction, draft curtains (similar to siding), metal laths to beams for fireproofing, enclosures for turbine generator sets, and threaded studs for various removable applications (fire extinguishers, etc.).

Table 5.4 For what applications does your company use power driven fasteners for connections to steel?

Response	Steel Erectors	Architects/Engineers
Metal roof decking for built-up roof systems (metal deck covered by materials such as waterproof membrane, insulation, gravel, etc.).	58%	59%
Metal roof decking for bare metal roofs .	33%	38%
Metal decking for concrete floors or roofs (metal decking covered by concrete).	50%	47%
Attachment of metal siding to steel members.	13%	44%
Attachment of pipes, ductwork, electrical conduit, etc., to steel members.	23%	50%
Attachment of hangars for suspended ceilings to steel members.	25%	50%

5.4 Advantages/Disadvantages

The major competitors of power driven fasteners are welds (primarily puddle welds) and self-drilling screws, for both structural and non-structural applications. As with screws, welds, or any other fastener, power driven fasteners have their share of advantages and disadvantages. These are discussed below.

5.4.1 Advantages of Power Driven Fasteners for Metal Decking Applications.

The main advantages of power driven fasteners when used for the connection of metal decking, cited by questionnaire respondents, are shown in Table 5.5.

The largest advantage of power driven fasteners, cited by respondents, is that they are installed more rapidly than other fasteners. Discussions with manufacturers have indicated that typical speeds of installation, in terms of fastening metal decking, are about 400-600 fasteners per hour for powder actuated fasteners and 1200-1500 fasteners per hour for pneumatically driven fasteners. It has been claimed that as many as 1800 fasteners per hour have been installed using pneumatically driven fasteners.

Table 5.5 For fastening of metal deck, what do you believe are the advantages of power driven fasteners as compared to other fasteners (i.e. screws or puddle welds)?

Response	Steel Erectors	Architects/Engineers
Power driven fasteners have a lower installed cost.	21%	38%
PDF are installed more rapidly.	50%	69%
PDF are more reliable.	13%	13%
Powder actuated fasteners do not need an external power source.	44%	34%
PDF do not destroy coatings on deck and/or base steel.	38%	28%
PDF can be installed in inclement weather (rain, snow, cold, etc.).	37%	31%
PDF quality can be more easily verified than screws or welds.	19%	16%

Power driven fasteners can be installed more easily in inclement weather (rain or snow) because of their lack of need for an electrical power supply. This can result in the avoidance of costly delays in a project due to weather conditions. This does not imply that power driven fasteners can be used safely and effectively under all weather conditions, as their could foreseeably be conditions that would prevent any work from being performed.

On projects were corrosion is a concern, the metal decking or base material may be specially coated. If welds are used, the welds may need to be painted. The portion of the deck immediately around the weld also may need to be touched-up to repair the coating destroyed by the welding. Further, coatings on the steel beams or joists that support the deck may be damaged by the heat of welding. Corrosion and damage to coatings are of less concern when power driven fasteners are used. Driving a fastener into steel does significantly less damage to the coating than welding.

An advantage that relates only to powder actuated fasteners is that no external power source is needed. This results in several advantages when compared with conventional fastening methods. The job-site becomes safer since there are no electrical cords or welding leads lying on the worksite. The lack of cords and welding leads also reduces the setup time involved in the job. The flexibility and mobility of the systems are increased. Finally, as noted earlier, fastener installation can be accomplished in a wider range of inclement weather.

Approximately one-quarter to one-third of the respondents indicated that they believe power driven fasteners have a lower installed cost than their conventional counterparts. The installed cost may vary depending on the building situation. The speed of the workers, weather conditions, specifications, labor costs and many other factors will all affect the installed cost of the system. A larger number of respondents indicated cost was a disadvantage of power driven systems, as discussed later in Section 5.4.2.

Most of the additional advantages cited by respondents related to welding rather than screws. Some individuals indicated that power driven fasteners are aesthetically more appealing than welds and they eliminate welding problems such as burn throughs and the emission of carcinogenic fumes. Small percentages of respondents indicated that reliability and verifiable quality were advantages of power driven fasteners. These are areas of concern that will be discussed in section 5.4.2 because many respondents indicated these areas as disadvantages.

Table 5.6 For fastening of metal deck, what do you believe are the disadvantages of power driven fasteners as compared to other fasteners (i.e. screws or puddle welds)?

Response	Steel Erectors	Architects/Engineers
Not familiar with power driven fasteners for metal deck.	6%	22%
Speed.	15%	3%
Cost.	50%	22%
Safety.	33%	25%
Base material (steel beam, joist or purlin under deck) is too thin.	25%	22%
Base material (steel beam, joist or purlin under deck) is too thick.	31%	16%
Problems with reliability and quality of connection (deck separates or breaks loose from fastener, fastener breaks, fastener unable to draw down deck into close contact with base material, etc.).	37%	44%
Don't like to use proprietary systems available from only a few manufacturers.	13%	13%

5.4.2 Disadvantages of Power Driven Fasteners for Metal Decking Applications. The main disadvantages of power driven fasteners for metal decking applications, cited by questionnaire respondents, are shown in Table 5.6.

Cost may be a significant barrier to the use of power driven fasteners. There is no contention among the power driven tool industry that the cost of the tools and fasteners are higher than those of conventional fastening methods. The manufacturers contend that the in-place cost of the fastener is lower than other fastening methods as the result of the increase in speed of the fastening system. Most of the architects/engineers did not indicate cost as a disadvantage. A large percentage of erectors, however, indicated that they believe cost to be a disadvantage.

Approximately one-quarter of the engineers and architects indicated they were not familiar with power fastening for metal deck attachment. Only 6 percent of the erectors were not familiar with power fastening of metal deck. This suggests that more information is needed on power fastening to steel that is specifically directed towards engineers and architects.

Again, safety is a large concern among the respondents. During conversations with engineers, erectors, and architects, the concern mentioned most frequently was safety. Many industry personnel believe these fastening systems to be unsafe; they are concerned about a fastener being shot through a deck and missing the structural framework.

Some professionals have indicated that they have had problems with the reliability of power driven fasteners. A problem cited is that the fasteners sometimes do not draw the decking down into contact with the base material. This problem could be due to inadequate nesting of the decking or due to an inadequate power load. If the base member is rather flexible (a long span joist or beam, for example), the fastener may deflect the base member rather than fully penetrating it. Several responses indicated that the fasteners sometimes tend to pull out, or the deck pulls-over the fastener head, when the decking is walked over and the decking is only tacked in place. Some respondents indicated that this a particular problem for very light gage decking (24 to 28 gage). Others indicated problems with fasteners pulling out at the corner where four deck sheets overlap.

Several respondents also question methods for verifying the quality of a fastening. The typical method for verifying fastener connections is by using a guide to check the pin standoff. According to this method, if the head of the fastener is between a maximum and minimum distance from the top of the attached material then it is adequate. In the case where the deck is not drawn down into contact with the base material, checking the pin standoff does not ensure that the fastener is adequately embedded in the base material. Some respondents also believe that there is not an approved or reliable method of inspection.

Small percentages of respondents indicated speed as a disadvantage. These comments seemed to be aimed at comparisons with welding rather than screws. Some respondents believe that welding is faster than power driven fasteners, at least, powder actuated fasteners.

5.4.3 Advantages/Disadvantages of Power Driven Fasteners for Applications other than Metal Decking. For applications other than metal decking, the advantages and disadvantages of using power driven fasteners, cited by questionnaire respondents, were similar to those discussed in sections 5.4.2 and 5.4.3. These questions were left open ended. Consequently, there was a wider variety of responses. Many of the advantages and disadvantages discussed in the previous sections can also be applied to applications other than metal decking. In addition, many advantages and disadvantages discussed below may also apply to metal decking applications. Responses related to speed and cost were virtually identical to those in the previous section and will not be discussed further in this section.

The responses relating to the reliability of power driven fasteners varied widely. Several respondents indicate that power driven fasteners are reliable and consistent fasteners that have very little waste (i.e., very low breakage), are easily inspected and verified and are less apt to come loose. They also indicated that hangars are fastened quickly, accurately and securely. Other respondents indicated that the fasteners bend or break, the studs cannot withstand much torque, uniform fastener strengths cannot be obtained and the fasteners are apt to come loose.

The remaining responses did not fall into any of the general categories listed above. They are listed here for reference purposes. The following responses were indicated as advantages:

- Simple serviceability of tools
- Wide variety of fasteners
- Less physical effort on the part of the worker - happier worker
- Availability
- Holding power
- Successfully used PDF for draft curtain installation (similar to siding); it is very helpful to achieve instant attachment once the sheet is positioned
- Advantageous in areas where certified welders are not available
- Ease of installation
- Very easy compared to drill & tap
- Don't like to drill through thick material
- Don't like to weld galvanized steel because of gases & promotes rusting
- Rigid connection without use of heat (welding)
- Operator training is faster than welding

The following responses were indicated as disadvantages:

- Permanent; nothing can be temporarily placed and then realigned for straight and true; if there is a change in plans, the plans are not complete, or a mistake is made the pins must be sheared off; screws are much easier to remove
- Lack of adjustment between fastener head and material attached to steel; loose connections cannot be tightened
- Requires more training and thought on how to make proper fastenings than other methods
- Experience with PDF has been very bad - inconsistency, cost, safety, etc; would not use PDF unless required by our customers

- Do not know how to assure proper installation other than by destructive testing
- Never used for anything but metal decking; main concern is lack of information on allowable loads for different applications & materials
- Base metal is sometimes too thick.

5.4.4 Fastener Preference. Questionnaire recipients were asked to rank their fastener preferences for attachment of metal deck. Table 5.7 shows the results. For the attachment of metal decking, both steel erectors and architects/engineers prefer puddle welds followed by screws, powder actuated fasteners and pneumatically driven fasteners. The column marked first indicates the percentage of respondents that ranked that fastener as their first choice and so on. One-third of the erectors and two-thirds of the engineers/architects indicated that puddle welds were their first choice for attachment of metal decking.

Table 5.7 Which type of fastener do you prefer for attachment of metal deck to steel beams, joists or purlins?

Response	Steel Erectors				Architects/Engineers			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th
Puddle Welds	33%	25%	6%	8%	63%	16%	6%	3%
Screws	21%	19%	19%	6%	22%	31%	9%	13%
Powder actuated	13%	15%	21%	8%	13%	22%	28%	6%
Pneumatic	10%	6%	10%	17%	0%	13%	22%	22%

5.4.5 Powder Actuated vs. Pneumatically Driven. Power driven fastening systems include both powder actuated and pneumatically driven fasteners. Pneumatic systems are faster than powder actuated systems since the power source is external (no need to load the power source). However, despite being faster than the powder actuated systems, they are used less extensively. The results from the steel erectors questionnaire showed that most of the systems being used are powder actuated. The sales personnel responses confirmed this trend as well.

5.5 Potential for Future Use

One question that was addressed in the architect/engineer questionnaire was whether power driven fastening had the potential for significantly increased future use. Eighty-six percent of the respondents indicated that power driven fasteners possess the potential for widespread use, while 7 percent said that they do not. The remaining 7 percent of the respondents remained neutral. Most respondents provided comments and/or opinions, which varied considerably. A few responses indicated current advantages that would help increase their use, such as:

- Speed and economy
- The ability to install in inclement weather
- The small amount of training required

Most responses indicated barriers that need to be overcome in order to obtain widespread use, which included:

- If it is explicitly included in more design specifications
- If the cost is reduced
- If it cuts labor costs, increases speed of construction, etc.
- If the safety and consistency aspects become more reliable
- If engineer/architect, inspectors, etc., were able to assure quality fastening by some relatively easy inspection method

- If more information was available on tests done comparing power driven fasteners with other types of fasteners (i.e., diaphragm tests comparing them with welded and screwed deck)
- If structural engineers are convinced of its ability to match the strength and longevity of welding or of mechanical fasteners

There were several general comments indicating the potential or the limitations of the systems:

- Insisting on better welding inspection would increase the cost of welding, thus promoting the use of power driven fasteners
- Contractor familiarity and training is needed as well as better manufacturer data for engineers
- More testing and actual field experience is needed
- It is quickly becoming more accepted; the quality is improving, contractors and building officials are becoming more familiar with power driven fasteners, building officials are accepting less documentation and the costs are coming down (equipment costs, training and learning curve)
- It has been used extensively by subcontractors (electrical, mechanical, sprinkler and plumbing) in attaching or supporting their components and only recently have requests been received to permit its use for attaching roof deck
- Use will probably increase slowly; more contractors use power driven fasteners now than thirty years ago

The potential for widespread use exists, but certain barriers must be overcome to increase the use of these systems. Methods of overcoming these barriers will be discussed in Chapter 6.

5.6 Additional Applications

As discussed in sections 2.3 and 5.3, power driven fasteners are used for a wide variety of applications. There are many other possible applications that are not currently widely recognized. Some additional application possibilities were provided by the questionnaire responses, which include: attaching liners in steel tanks; fastening bar codes to railroad cars; fastening wire mesh to steel in the steel beam fireproofing process; draft curtain installation; attachment of exterior trim, facia, guttering, etc.; permanent attachment of informational signage on parking facilities and transportation facilities; attaching plywood diaphragms to steel structures; and attaching light bracing members. Power driven fasteners are currently being used for all these applications in a very limited capacity. These applications are potential areas for more extensive use of power driven fasteners. Other possible future applications are discussed in Chapter 6.

CHAPTER 6

POWER DRIVEN FASTENERS: NEEDS AND OPPORTUNITIES

6.1 Overview

Power driven fastening to steel has a significant potential for increased use in the U.S. construction industry. However, there appear to be several significant barriers to increased use at present. In this chapter, recommendations are made for actions that will help overcome these barriers. New areas of application will be considered, along with research and testing needs. The recommendations and suggestions provided in this chapter combine information collected in the industry survey (Chapter 5), the literature survey (Chapter 3), the overview of fastener capabilities (Chapter 4), and the opinions and judgements of the authors.

6.2 Recommended Actions for Increased Use of Power Driven Fastening

Power driven fastening to steel is a well developed technology that has been available in the U.S for over 50 years. This technology has a strong basis in research and testing. Yet, power driven fastening is not widely recognized in the U.S., and is not being used to its full potential. In this section, some of the major barriers to increased use of power driven fastening to steel are considered, along with recommended actions for overcoming these barriers.

Address the Information Needs of the Engineering and Technical Community.

In the opinion of the authors, the single largest barrier to increased use of power driven fastening to steel is the nearly complete lack of information on this technology available to the technical community in the U.S., i.e, engineers, educators, and researchers. The primary source of information available in the U.S. is sales literature provided by manufacturers. Sales literature provides little genuine technical data, other than recommended allowable fastener strength values, and does not adequately address the information needs of the technical community. The sales literature and the marketing efforts of the manufacturers have been directed primarily towards the end user, i.e., construction contractors. Little attention has been given to the needs of those who design, specify, teach, or conduct research on fastening systems.

The lack of available information is clear from the literature search and from the survey results. The consequences of this lack of information are also evidenced in the results of the industry survey. Most of the engineers surveyed had heard of power driven fastening, but 50% indicated they didn't know enough to feel comfortable using this technology (Table 5.2). Only 19% included power driven fasteners explicitly in their construction specifications (Table 5.3). Contractors indicated that the engineer's specifications play a large role in the choice of fastening system. Even if a contractor prefers to use power driven fasteners, the process of requesting their approval from the engineer can be a difficult and time consuming process. Thus, the absence of power driven fasteners in engineers' specifications is a significant barrier to their use, and is a direct result of neglecting the information needs of engineers.

The most striking evidence of the consequences of inadequately disseminated technical information is found in fastening preferences for metal decking. Attachment of metal decking is currently the single most important application of power driven fasteners. Yet, 85% of engineers indicated that welds or screws were their preferred method for fastening deck (Table 5.7). Addressing the information needs of the engineering and technical community is likely to significantly increase the use of power driven fasteners in currently recognized applications, such as metal deck attachment. It is also likely to stimulate the development of new applications.

The information needed by the technical community is not addressed by currently available sales literature. Information and literature provided to engineers must have a strong technical orientation. Performance claims must be substantiated by research and test data that is easily available and understandable. Design guidelines and examples must be provided.

Following are specific suggestions for addressing the information needs of the engineering and technical community:

- *Develop a Technical Guide for Power Driven Fastening to Steel.*

It is clear from the literature survey that a great deal of research and testing has been conducted on power driven fastening to steel. This information, however, is largely inaccessible. Some of the information is not made available due to proprietary concerns. However, a great deal of non-proprietary research and testing data is available, but is not in a form that is accessible or useable by engineers.

It is recommended that a *Technical Guide to Power Driven Fastening to Steel* be developed as a primary source of technical data for engineers, educators, and researchers. Such a guide should, in a single document, condense and summarize research and testing data for power driven fasteners. It should include design recommendations and examples, where possible. The focus of the guide should be technical in nature, with a minimum of sales oriented content.

The writers of such a guide should likely come from within the power driven fastener industry, since this is where the technical expertise largely resides. The guide could be developed by the combined efforts of several manufacturers, or by a single manufacturer. Independent reviews should be provided from outside of the industry to assure the technical integrity and credibility of the document.

There are several examples of technical guides from other industries that could be used as a model for a power driven fastening guide. These include:

- *Guide to Design Criteria for Bolted and Riveted Joints,* by G. Kulak, J. Fisher, and J. Struik, published by John Wiley and Sons, 1986.
- *Wood Handbook: Wood as an Engineering Material,* published by the U.S. Department of Agriculture Forest Products Laboratory.
- *Diaphragm Design Manual,* published by the Steel Deck Institute, 1990.
- Technical publications on welding published by the Lincoln Electric Company, including: *Design of Welded Structures,* and *The Procedure Handbook of Arc Welding.*
- *The Welding Handbook,* published by the American Welding Society.

Each of the above examples successfully summarizes technical information in a format useful to engineers, and include design recommendations and examples. The development of a similar technical guide for power driven fastening to steel will contribute greatly to increased use of this technology in the U.S.

- *Disseminate the results of research and testing programs in U.S. engineering literature and conferences.*

  A primary means of disseminating technical information is by publication in engineering journals and conference proceedings, and by presentation at engineering conferences. Very few research results on power driven fastening to steel have been published in U.S. engineering literature or presented at U.S. engineering conferences. The power driven fastener industry should encourage its researchers to publish nonproprietary research results, particularly for projects conducted by university researchers. The literature search revealed a number of research and test reports from European universities. These researchers should be encouraged to publish and present their work in the U.S.

  Examples of important U.S. journals and conferences include:

- *Journal of Structural Engineering,* published by the American Society of Civil Engineers (ASCE). This monthly journal has a very wide distribution among structural engineers, educators, and researchers in the U.S. and worldwide.
- *Engineering Journal,* published by the American Institute of Steel Construction (AISC). This journal, published quarterly, has a wide distribution among engineers, educators and researchers involved with steel construction in the U.S.
- *The National Steel Construction Conference,* sponsored by AISC, and *The Structures Congress*, sponsored by ASCE. These annual conferences and their proceedings provide opportunities for widespread dissemination of technical information on power driven fastening.

Presentation and publication of research results at selected specialty conferences, such as those related to cold formed construction, provide additional opportunities.

- *Include power driven fastening data in the AISC Manual of Steel Construction.*

  The Manual of Steel Construction is the most widely used design manual for steel construction in the U.S. Virtually every designer, educator, student, and researcher involved with steel construction uses this manual. This manual includes technical data on bolts and welds, but contains no information on power driven fastening. It is recommended that the power driven fastener industry work with AISC to explore the possibility of including power driven fastener technical data in the manual.

Address Safety Concerns.

The industry survey revealed that safety of power driven fastening is a major concern among engineers and construction personnel. There is a widespread perception that power driven fastening is inherently more dangerous than many other construction operations. This perception represents a significant barrier to increased use of power driven fastening.

Discussions with engineers and construction personnel suggest that concerns about safety are based largely on perceptions rather than on actual experience or on accident statistics. No accident statistics for power driven fastening were found as part of this study in order to confirm or refute safety concerns. However, no information was found to support the perception that power driven fastening is unsafe. In the opinion of the authors, the power driven fastening industry has put significant emphasis on safety in the design of their systems.

Concerns and misconceptions about safety must be addressed to overcome this barrier. Many of the safety concerns can likely be addressed by more widespread dissemination of information about power driven fastening. Much of this information, such as discussions on low velocity versus high velocity tools, and recommended safe operating practices, are already included in sales and product literature and in the PATMI *Powder Actuated Fastening Systems Basic Training Manual.* Safety related articles have also been published in various trade magazines (see the Safety section of Appendix A). Greater exposure of this information to a broader audience is needed.

To further address safety concerns, it is also recommended that the results of specific safety related studies be published. For example, studies on the safety consequences of shooting the fastener through metal deck, when the fastener misses the base material, should be published. Publishing both general safety related articles, as well as conducting and publishing the results of specific studies and tests, should address many of the safety concerns of engineers and of the construction industry.

Develop an Industry Association.

PATMI (Powder Actuated Tool Manufacturers' Institute) currently represents the powder actuated fastening industry in the U.S. The primary goal of PATMI is operator safety, as stated in the PATMI *Powder Actuated Fastening Systems Basic Training Manual.* It is recommended that the scope of PATMI's mission be enlarged, or a new industry association be developed, to more actively represent power driven fastening.

A strong and active industry association can support a number of activities that will contribute to increased use of power driven fastening to steel in the U.S., including:

- Develop technical literature, design guides, etc.
- Develop consensus based standards for fasteners, test methods, inspection methods, etc.
- Represent power driven fasteners in code and specification writing bodies, such as ICBO, AISC, ASTM, etc.
- Promote education and information dissemination.

It is recognized that the companies that make up the power driven fastening industry are highly competitive, and have significant proprietary concerns. Nonetheless, many other highly competitive industries have recognized the benefits of forming industry associations. Examples within the steel industry include the Steel Deck Institute and the Steel Joist Institute. The formation of such an association for the power driven fastening industry is likely to benefit the entire industry.

Develop Nonproprietary Standards for Fasteners.

Power driven fasteners for steel are not standardized in the U.S. Each manufacturer offers their own line of fasteners. Thus, a user of power driven fasteners must specify a particular manufacturer's product, rather than specifying a nationally recognized standard.

Developing some degree of standardization for fasteners is likely to contribute to increased use of power driven fastening for steel. Standards simplify the design and specification process, since an engineer need not be familiar with the product line of each manufacturer. Some engineers are also more likely to use a product for which standards exist. The existence of recognized standards also facilitates the adoption and inclusion of power driven fasteners in building codes.

It is recommended that the power driven fastener industry work towards the development of national consensus based standards for power driven fasteners. An appropriate location for such standards is within ASTM. ASTM standards are widely recognized and used within the U.S., and permit the most broad based acceptance. A possible format for a power driven fastener standard is the development of fastener grades, where performance based criteria are established for each grade, as measured by standardized tests.

Develop Consistent Factors of Safety.

At present, there is a rather inconsistent use of factors of safety for power driven fasteners. For the same type of fastener under the same type of loading, different factors of safety are sometimes used by different manufacturers. Further, various code approval agencies (ICBO, BOCA, Factory Mutual, etc.) may use factors of safety that differ from those recommended in manufacturers' product literature.

It would be in the best interest of the power driven fastener industry to work towards a consistent set of safety factors that would be acceptable to all code agencies. An engineer may be reluctant to use power driven fasteners if there are different safety factors required by different agencies. The existence of different safety factors makes the designers wonder if there are some limitations to the systems that they do not know about.

Why should designers feel confident in using the allowable values given by the manufacturer in a non ICBO area, if ICBO requires a lower allowable value? Are the fasteners less reliable than the manufacturers claim? Developing consistent accepted safety factors will help to eliminate some of the doubts about these systems and simplify the design process.

At present, it appears that factors of safety are chosen in a somewhat arbitrary manner. The power driven fastener industry must agree upon a rational methodology for establishing factors of safety that is acceptable to code agencies. Methods are available for establishing factors of safety based on reliability theory.

Most codes and specifications in the U.S. and worldwide are moving away from traditional factor of safety based allowable stress design methods. The load and resistance factor design methodology is the preferred format for many current codes, and is likely to be the preferred design format for virtually all codes in the future. With this design format, a "resistance factor" is used rather than the traditional factor of safety. The power driven fastener industry must therefore also work towards the development of consistent and rational resistance factors for their fasteners.

Additional Recommendations.

This section provides some additional recommendations for increasing the use and acceptance of power driven fastening to steel. The recommendations are based on comments received in the industry survey.

- Develop more durable and rugged tools that require less maintenance.
- Develop an improved inspection method for installed fasteners.

  Some industry representatives indicated that there are some problems with current inspection methods. Measuring the standoff of the fastener head does not necessarily ensure that the fastener is adequately embedded in the base material, since there could be a space between the two elements.

- Provide guidance for choice of power loads.

  At present, product literature recommends power loads be chosen on a trial and error basis, starting with the smallest power load, and working up until adequate penetration has been achieved. Some of the survey respondents suggested that a chart be provided, indicating suggested power loads to obtain adequate penetration for common deck gauge and base material thickness combinations.

- Conduct Cost Studies.

  As noted earlier, the primary current application of power driven fastening to steel in the U.S. is attachment of metal deck, primarily roof deck, to steel beams and joists. The cost of using power driven fasteners for metal deck attachment, versus the cost of using welds or screws, has a large impact on the choice of fastening system. The results of the industry survey suggested there was no general consensus among steel erectors or among engineers about which was the most cost effective system. Discussions with erectors and engineers suggested that their opinions regarding cost were generally not based on detailed and comprehensive cost comparisons. Rather, opinions regarding cost were often based on perceptions or based on the cost of the fasteners, without properly considering cost items such as speed of installation, inspection costs, costs of touching up damaged coatings, weather delays, etc. Thus, it would be useful to conduct several detailed and comprehensive cost "case studies." These studies might consider typical roof deck on steel joist installations, for various size roofs and various geographic locations in the U.S. The studies should compare final installed cost of the roof system for various fastening system choices, using representative current labor and material rates. It is recognized that such cost studies have significant limitations. Some cost factors are difficult to quantify, or become out of date very quickly. Nonetheless, several carefully conducted cost studies would provide a more quantitative basis for use by engineers and contractors for choosing a fastening system.

6.3 Possible Future Applications

It is clear from the industry survey (Chapter 5) that the primary current application of power driven fastening for steel in the U.S. is metal deck attachment in building floor and roof systems. It also appears from the industry survey that there is still significant potential for increased use of power driven fastening in this area. Beyond metal deck attachment, there appear to be a variety of other, largely nonstructural applications of power driven fastening for steel. These include the attachment of ductwork, pipe hangers, suspended ceiling hangers, metal studs, etc. Some additional current and future applications of power driven fastening were also suggested by the mail survey respondents. These suggestions were listed in Section 5.6.

This section will consider some additional possible new areas of application and new directions for power driven fastening to steel in the U.S., not considered previously in this report.

Heavier structural steel connections

Power driven fasteners are currently used largely for connecting relatively thin steel elements. The surface steel element is generally very thin, typically less than about 0.1 inch in thickness. The base material is also generally thin, typically on the order of 1/8 to 3/8 inch in thickness. The use of thin materials is a consequence of two factors. First, the use of low velocity tools limits the thickness of steel that can be penetrated. Secondly, power driven fastener manufacturers recommend that fasteners fully penetrate the base material in order to achieve maximum holding power. This recommendation also limits the thickness of material that can used with power driven fasteners.

Developing the technology to connect steel elements that are somewhat thicker than those used in current applications will permit the use of power driven fasteners for heavier structural steel connections. A wide range of new applications for power driven fasteners could then potentially be developed.

One approach for connecting thicker steel elements is to drive the fastener through predrilled holes in the surface element. The holes could be slightly smaller in diameter than the fastener, in order to provide a tight, slip resistant connection. Alternatively, the holes could be slightly larger than the fastener. A threaded stud could then be driven through the hole, with a nut used on the threaded stud to hold the surface plate in place. Such a connection could be used in non-slip critical shear type connections. An additional approach for connecting thicker elements could be to first drive threaded studs onto the base material. The surface element, provided with predrilled holes, could then be placed over the studs, and held in place with nuts on the threaded studs.

With the approaches suggested above, it may be possible to connect surface steel elements with thicknesses on the order of 1/4 to 5/8 inches, or more. The ability to connect elements in this thickness range could substantially broaden the use of power driven fasteners for use in heavier structural steel applications. (Some potential applications are discussed later in this section). From the overview of fastener capabilities considered in Chapter 4, it appears that many of the available power driven fasteners have tensile and shear capacities that are suitable for use in heavier structural steel connections. Additional research and testing may be required, however, to establish the capabilities and limitations of power driven fasteners when connecting thicker steel surface elements through predrilled holes. Modifications would also be needed to the installation tools in order to permit an operator to guide a fastener into a predrilled hole.

The use of power driven fasteners for heavier structural steel connections could also be enhanced by increasing the thickness of base material that can be connected with these fasteners. As noted above, fastener manufacturers, in their product literature, recommend that the fastener fully penetrate the base material. The fastener data presented in Chapter 4 support this recommendation. That is, it appears that larger and more consistent tensile and shear capacities result when the fastener fully penetrates the base material. However, it also appears that the fasteners still have substantial capacities even when they do not penetrate the base material, i.e., when the fastener tip remains embedded in the base material. By more accurately quantifying fastener load capacities for this situation, it may be possible to extend the range of power driven fastener use for thicker steel base materials.

Rehabilitation of Existing Steel Structures

The U.S. has a large inventory of older building, bridge, and industrial structures. In the future, a great deal of construction activity in the U.S. is likely to be related to rehabilitation of existing structures. This includes repair and restoration of damaged or deteriorated structures; and strengthening of existing structures to carry new or increased loads.

Power driven fastening may be a very attractive technology for repair and strengthening of older steel structures. In these applications, power driven fasteners may offer some potentially important advantages over conventional bolting or welding. Power driven fasteners may be advantageous in areas of limited access or tight working clearances, in areas where connections must be made overhead (where welding is difficult), or in areas where access is provided on only one side of a steel member (where bolting is difficult). The speed with which power driven fasteners can be installed may also be advantageous for minimizing the disruption to a structure under renovation.

Possible applications of power driven fasteners include the attachment of steel cover plates for strengthening steel members or for patching corroded areas. Connections in existing steel structures could also potentially be strengthened by the use of power driven fasteners. The attachment of secondary bracing members, stiffeners, or doubler plates are additional potential applications of power driven fasteners in a rehabilitation project.

Many older steel structures were constructed by building up members from relatively light and thin steel plates and shapes. Thus, the typical material thicknesses found in many older steel structures are within the range of application for power driven fasteners. New steel elements, such as cover plates, attached to an existing steel structure, could also be relatively thin, perhaps in the range of 3/8 to 1/2 inch. The development of the technology for fastening surface materials in this thickness range, as suggested above, is likely to be an important prerequisite for widespread application of power driven fastening in rehabilitation applications.

Connections in Metal Building Systems

Metal building systems are widely used in the U.S. for low rise commercial and industrial buildings. These buildings are typically constructed with light gauge metal roofing and siding that is attached to somewhat heavier gauge steel purlins and girts. The purlins and girts are then attached to the main structural members. The main structural members are typically arranged to form a gable frame, and are constructed of welded I shaped steel members.

The attachment of metal siding and roofing in metal building systems is generally not well suited to power driven fastening. The purlins or girts to which the siding and roofing are attached are typically too thin to serve as a base material for power driven fasteners. However, the attachment of the purlins and girts to the main structural steel members is a potential application of power driven fasteners. The main structural members are typically in the range of 1/4 to 5/8 inch in thickness, and are therefore suitable to serve as a base material for a power driven fastener. The purlins and girts are often less than about 0.1 inches in thickness, and therefore are also well suited for attachment with power driven fasteners. An additional potential application of power driven fastening is the attachment of secondary bracing members to the main structural members.

Applications in Bridge Structures

To the knowledge of the authors, power driven fasteners have not been applied to steel bridge structures in the U.S. The literature review revealed an application in Europe, in which power driven fasteners were used to attach sound insulating materials to a steel railway bridge. There also appear to be potential applications of power driven fasteners for steel bridges in the U.S. These include the attachment of metal decking (used as "stay in place" forms for the concrete bridge deck), the attachment of signs, railing, utility supports, and other nonstructural elements. As noted earlier, power driven fasteners could also potentially be used for repairing or strengthening older deteriorated steel bridges.

Shear Connectors for Composite Joists

The literature review revealed that a significant amount of research has been conducted on cold formed steel shear connectors for composite beams. The shear connectors are attached to a steel beam with power driven fasteners, and provide shear transfer between the concrete deck and the steel beam. These cold formed shear connectors are intended as an alternative to the more conventional welded shear stud.

Despite the large amount of research conducted on cold formed shear connectors, the industry survey suggested very little use of these connectors in the U.S. These connectors do not appear to be economically competitive at present with welded shear studs for conventional composite beam construction using rolled wide flange steel beams.

Cold formed shear connectors attached with power driven fasteners may be potentially more competitive for use in composite joists. The use of open web steel joists is becoming increasingly popular in U.S. building construction in lieu of rolled wide flange sections. Joists are commonly used as roof beams, and are also being used increasingly as floor beams. Along with the increasing use of steel joists is the use of composite joists. In composite joists, the steel joist is connected to the concrete floor deck with shear connectors. The typical thicknesses of joist top chord members are ideally suited for power driven fastening. With power driven fasteners, there is no risk of burn through, as there might be when shear studs are welded to the thin joist chord members. Further, the shear connector forces may often be less in composite joists as compared to composite wide flange beams. These lower forces are more in line with the capacities of cold formed shear connectors.

Connections to Hollow Structural Sections

Hollow structural sections (square, rectangular, and circular steel sections) are frequently used in low rise steel construction as columns. These sections are also sometimes used as truss or bracing members. Hollow structural sections are chosen over more conventional open shapes for a variety of reasons, including structural efficiency and aesthetics. Further, it appears that the use of hollow structural sections is increasing in the U.S.

Connections to hollow structural sections is a potential area of application for power driven fasteners. Power driven fasteners do not require access to the inside of the member in order to make the connection (as compared to conventional bolts). Further, the thickness of commercially available hollow sections in the U.S. is in the range of 3/16 to 5/8 inch, making them candidates for power driven fastening. Power driven fasteners could potentially be used to attach connection plates or gusset plates, on the order of 1/4 to 1/2 inch in thickness, to hollow sections.

6.4 Research Needs

In this section, suggestions are made for additional areas of research related to power driven fastening for steel. It is believed that additional research will provide information and data that will lead to the expanded use of this fastening technology. Research and testing may already be available for some of the topics listed below, but was not readily apparent or available to the authors. Consequently, the items listed below can be considered as areas where additional research is needed, or where existing research needs further synthesis or dissemination.

- *Clarify the effects of the following variables on fastener tensile and shear capacities: Base metal yield and tensile strengths, depth of fastener penetration (for cases where fasteners penetrate the base material, as well as for cases where the fastener does not fully penetrate the base material), and fastener knurling.*
  These variables have been considered to varying extent in many testing programs. However, the available data needs to be synthesized in order to clearly quantify the effect of these variables on fastener capacity. Currently available manufacturers' product literature is unclear on these points.

- *Characterize the force-deformation response of fasteners under various loading conditions.*
  The majority of test reports and product literature provide information on the ultimate strength of fasteners under shear or tensile loadings. Little or no

information, however, is provided on the overall force-deformation response of the connection prior to failure. Thus, no information is available on the stiffness and ductility of connections made with power driven fasteners. Information on the entire force-deformation history of the connection, rather than just ultimate strength, is useful when evaluating the suitability of power driven fasteners for new applications.

- *Investigate the behavior of multiple fastener connections.*

  The vast majority of test data on fastener shear and tensile capacities and surface material pull over capacities are for single fastener installations. Data is required on the capacity of connections made with multiple fasteners. Items of particular interest include the distribution of forces to the individual fasteners at various stages of loading, the ability to redistribute forces among the fasteners, and the stiffness, ductility, and ultimate capacity of the connection. This data is of particular interest for connections made with somewhat thicker surface materials, in the range of 1/4 to 1/2 inch.

- *Investigate fastener capacity under combined shear and tensile loading.*

- *Develop behavioral models to predict fastener capacity under various loading conditions.*

  Fastener capacities are currently determined in an empirical manner based on extensive test programs. Future application of power driven fasteners would be facilitated by the development of simple behavioral models and equations for predicting fastener capacity. Models are needed to predict the strength of power driven fastener connections for fundamental limit states such as fastener pull out, fastener fracture, material bearing failure, and material pull over failure. Behavioral models do not replace testing. Rather, the availability of simple behavioral models can greatly enhance and extend the range of application of test data.

- *Investigate the influence of the base material state of stress on fastener capacity.*

  The majority of fastener test data is for cases in which no significant external load in present on the base material. It is unclear if fastener capacity is affected by the presence of large stresses, particularly tensile stresses, in the base material. As an example, consider a power driven fastener installed in the tension flange of a beam. If the beam has developed its plastic moment at that location, or if the beam has undergone cyclic yield reversals (due to earthquake loads), is the fastener pull out capacity affected?

- *Investigate the influence of power driven fasteners on base material behavior.*

  The effect that a power driven fastener has on the structural capacity of the base material in unclear. The literature search revealed some limited testing on the effect of power driven fasteners on base material strength for simple loading cases. However, there appear to be no methods available to actually calculate the loss in load capacity in the base material. Of particular interest is the effect of power driven fasteners on the cyclic loading strength or ductility of the base material. Some data was found in the literature search on the effect of power driven fasteners on the high cycle - low stress fatigue life of the base material. This data needs to be synthesized and extended for consideration of power driven fasteners in steel bridge applications. Data is also needed on the effect of power driven fasteners on the low cycle - high stress behavior of the base material. For applications in earthquake resistant structures, it is necessary to know if the presence of power driven fasteners in plastic hinge regions affects the ductility that can be developed at the hinges.

- *Investigate the behavior of composite open web steel joists constructed with cold formed shear connectors.*

6.5 Concluding Remarks

Power driven fasteners for steel appear to have the potential for significantly increased use in the U.S. construction industry. Some barriers need to be overcome, however, to reach the ultimate potential of these systems. Foremost among these is the need to address the information needs of the engineering and technical community in the U.S. The large body of research and testing available on power driven fastening to steel must be synthesized and disseminated in a form useful to engineers, educators, and researchers. The power driven fastener industry in the U.S. has put significant effort towards introducing and marketing their product to construction contractors. A similar effort, but with a more technical emphasis, is needed for engineers. An active program for disseminating technical information, directed towards the engineering and technical community in the U.S., provides the best opportunity for increasing the use of power driven fastening in currently recognized applications such as metal deck attachment, as well as for stimulating the development of new applications.

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