APA

The Engineered Wood Association

INDUSTRIAL USE GUIDE

TRANSPORT EQUIPMENT

A P A

The Engineered Wood Association

DO THE RIGHT THING RIGHT™

Wood is good. It is the earth's natural, energy efficient and renewable building material.

Engineered wood is a better use of wood. It uses less wood to make more wood products.

That's why using APA trademarked I-joists, glued laminated timbers, laminated veneer lumber, plywood and oriented strand board is the right thing to do.

A few facts about wood.

- *We're not running out of trees.* One-third of the United States land base – 731 million acres – is covered by forests. About two-thirds of that 731 million acres is suitable for repeated planting and harvesting of timber. But only about half of the land suitable for growing timber is open to logging. Most of that harvestable acreage also is open to other uses, such as camping, hiking, hunting, etc.

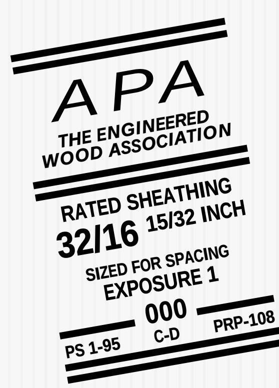
- *We're growing more wood every day.* American landowners plant more than two billion trees every year. In addition, millions of trees seed naturally. The forest products industry, which comprises about 15 percent of forestland ownership, is responsible for 41 percent of replanted forest acreage. That works out to more than one billion trees a year, or about three million trees planted every day. This high rate of replanting accounts for the fact that each year, 27 percent more timber is grown than is harvested.

- *Manufacturing wood is energy efficient.* Wood products made up 47 percent of all industrial raw materials manufactured in the United States, yet consumed only 4 percent of the energy needed to manufacture all industrial raw materials, according to a 1987 study.

Material	Percent of Production	Percent of Energy Use
Wood	47	4
Steel	23	48
Aluminum	2	8

- *Good news for a healthy planet.* For every ton of wood grown, a young forest produces 1.07 tons of oxygen and absorbs 1.47 tons of carbon dioxide.

Wood. It's the right product for the environment.



NOTICE:
The recommendations in this guide apply only to panels that bear the APA trademark. Only panels bearing the APA trademark are subject to the Association's quality auditing program.

APA trademarked plywood has been indispensable to transport equipment manufacture for nearly 50 years. It has earned a sterling reputation as a lightweight, reliable and cost-efficient structural material. In trucks, trailers, intermodal containers, rail cars, pickup trucks and recreational vehicles of all kinds, plywood and other wood structural panels represent the logical choice for bodies, linings, interior cabinetry and numerous other applications.

This manual is for transport equipment designers, engineers and manufacturers. It covers APA trademarked wood structural panel grades and properties, structurally overlaid panels, design criteria, fastener data and other key topics.

Since the design of transport equipment is an intricate and evolving science, this publication does not present complete unit designs. It does, however, provide the most recent and accurate criteria available on appropriate wood structural panel design aspects. Final decision on suitable performance level is left to the design engineer.

CONTENTS

Conventional Plywood

Strength And Stiffness.

Plywood manufactured under *U.S. Product Standard PS 1 for Construction and Industrial Plywood* may be made from over 70 species of wood. These species are divided by strength and stiffness into five groups. Group 1 species are the strongest and stiffest, Group 2 the next strongest and stiffest, and so on. The group number in the APA trademark is part of the correct grade designation for the sanded panels commonly recommended and specified for transport lining and recreational vehicle applications.

The strength of wood along the grain is many times greater than across the grain. By cross-laminating layers of veneer, plywood provides along-the-grain strength in both directions. Yet relative to its strength, plywood is a relatively lightweight material and can thus help minimize tare – an important consideration in all transport applications. The relative strength of plywood lining panels is given in *Table 1.*

Plywood also exhibits excellent stiffness, or resistance both to deflection under uniform and concentrated loads and to racking forces. This stiffness often permits plywood to be used with less framing or bracing than other materials may require.

Plywood withstands heavy concentrated loads because the cross-lamination distributes stress over a wide area.

Table 2 provides concentrated load strength information for Group 1 sanded plywood thicknesses.

Span length within the limits normally associated with a plywood thickness has minimal influence on concentrated load capacity. Loads applied to a free unsupported edge may be 50 to 90 percent of the load shown for center panel locations. If applied by a four-inch disc, loads may be 20 to 50 percent greater than those charted.

Plywood also can withstand repeated impact without cracking or crumbling because of its cross-laminated construction. Since it has no plane of cleavage, it's extremely resistant to splitting.

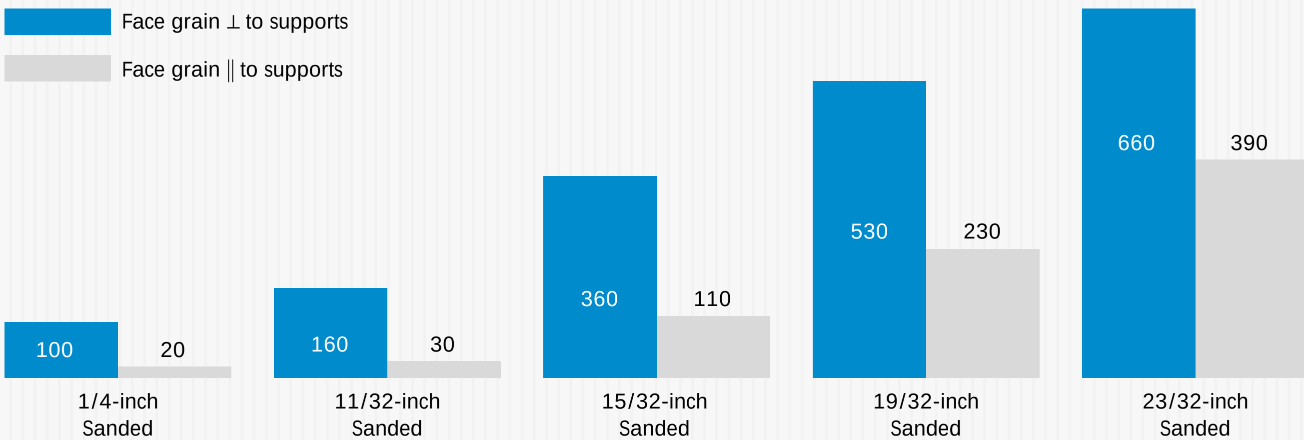
Table 3 documents plywood resistance to forklift tine penetration, a major cause of truck liner damage. According to tests of different thicknesses, face grain direction of a panel only slightly influences total tine penetration resistance. The impact resistance of a bare 1/4-inch plywood panel can be doubled by substituting a special 1/4-inch plywood liner panel with 0.050-inch-thick (1.5 oz/sq ft) fiberglass mat face. Thicker plywood with more glass increases penetration resistance proportionately.

APA Performance-Rated Panels

Wood structural panels of compositions and configurations other than conventional all-veneer plywood are also available from APA member mills. These

TABLE 1

RELATIVE STRENGTH OF PLYWOOD LINING PANELS



Group 1 species are most commonly used as lining. Group 2 and 3 plywood is 73% as strong and Group 4 is 67% as strong. The table above is valid for comparing panels within any one species Group.

panel products are manufactured according to APA performance standards that set strength, stiffness and durability criteria for specific construction applications. Panels include oriented strand board (OSB) and composites (reconstituted wood cores bonded between veneer faces).

Abrasion Resistance. In truck lining applications wood structural panels provide a smooth surface with relatively few joints, making it ideal for sliding and skidding palletized and loose-loaded freight. Snag-free panel surfaces reduce costly damage to boxed and bagged goods and possess high resistance to prolonged friction and abrasion.

For extra protection against fork tine damage, replaceable scuff panels are often installed over the bottom two feet

TABLE 2

CONCENTRATED-LOAD STRENGTH – 2 INCH LOADING DISC
Face Grain Across Supports

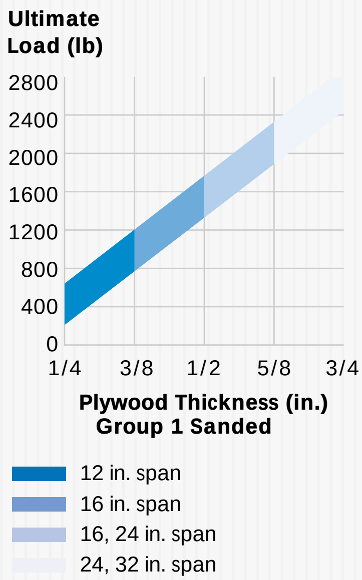
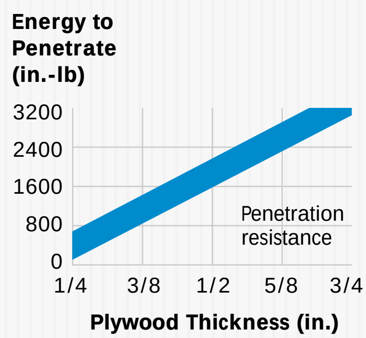


TABLE 3

FORK TINE PENETRATION RESISTANCE
Round tip fork tine 1/2 in. x 5 in. penetrating Group 1 plywood on supports 16 in. o.c.



of a liner. *Table 4* rates the surface scuff resistance of typical plywood panels used in lining applications. To establish a comparative scale, bare APA trademarked A-C Group 1 plywood has been given a rating of 100. Remember that scuff panel performance depends upon solid wood structural panel backing. Without such backing, a scuffing load will quickly penetrate a lining.

Dimensional Stability. APA trademarked plywood is an engineered product with known, predictable properties. Press-dried at the mill, it is never "green." And by restricting expansion and contraction within individual plies, its cross-laminated construction helps deliver exceptional dimensional stability in the plane of the panel. From oven-dry to maximum saturation, plywood panels swell an average of only 2/10 of one percent in length or width. Plywood therefore remains intact and strong under extremes of temperature and moisture.

Workability. Wood structural panels are easily worked with ordinary tools. They take and hold fasteners – even near panel edges – without splitting. Wood structural panels' workability and strength properties permit great latitude in placement of interior hardware, such as required for cargo restraint devices, shelving, or dividers.

Thermal, Acoustical And Fire-Resistant Properties. A wood structural panel is a natural insulator, a good sound barrier and an effective fire resister. Large panel size minimizes the number of joints that can lose heat or refrigeration, "leak" airborne noise or allow flame passage.

The ability of a material to retard heat flow is termed thermal resistance (R). The R values of several panel thicknesses are given in *Table 5*.

The burn resistance requirements for materials used in the occupant compartments of motor vehicles are specified in the *Federal Motor Vehicle Safety Standard No. 302, Flammability of Interior Materials in Passenger Cars, Multipurpose Passenger Vehicles, Trucks and Buses.* Tests conducted at the APA research laboratory have shown that plywood of various thicknesses and with face grain oriented both parallel and perpendicular to the long dimension of the specimen easily meets the requirements of *Motor Vehicle Safety Standard No. 302.* Results in all tests showed a burn rate of zero as measured by the standard's requirements. In no instance did the flame reach the 1-1/2-inch starting mark of the specimen before self-extinguishing.

Compatibility. Wood structural panels can be used in combination with other wood products, metals or plastics. They will not contribute to electrolytic action when used with metals. They won't rust or corrode, even when exposed to harsh chemicals. They bond with many durable adhesives. And they accept a wide variety of field-applied finishes, including conventional paints, stains and varnishes, as well as vinyls, epoxies and latex-based products.

Availability. APA trademarked panels are available throughout North America in a wide variety of thicknesses, types and grades. Besides the standard products, coated and overlaid plywood panels have gained wide acceptance in the transportation industry. High Density Overlay (HDO), for example, has a resin-impregnated fiber overlay that provides a smooth, highly chemical-resistant surface.

TABLE 4

SURFACE SCUFF* RESISTANCE RATING

Panel	Rating
Common plywood linings	
Bare Group 1 plywood (A-C)	100
High density overlay Group 1 plywood (HDO A-A)	100
Coated liner panels	
0.050-inch-thick FRP bonded to plywood	189
0.030-inch-thick FRP bonded to plywood	167
Structural overlaid composites	
2.67 oz/sq ft (24 oz/yd) woven roving on plywood	211
2.00 oz/sq ft chopped roving SMC on plywood	178
Scuff panel over plywood backing	
0.120-inch-thick FRP scuff panel, plywood backing	400
0.100-inch-thick FRP scuff panel, plywood backing	267
Less used plywood linings	
Bare Group 2 plywood (A-C)	89
Bare Group 4 plywood (A-C)	67

*Comparative resistance to face damage from a load applied through a 3/4-inch-diameter hemispherical steel loading head dragged across the surface.

TABLE 5

WOOD STRUCTURAL PANEL THERMAL RESISTANCE

Panel Thickness (in.)	Thermal Resistance (R)
1/4	0.31
5/16	0.39
3/8	0.47
7/16	0.55
1/2	0.62
5/8	0.78
3/4	0.94
1	1.25
1-1/8	1.41

FRP Plywood

Plywood panels overlaid with structural faces of fiberglass-reinforced plastic (FRP plywood) combine the proven qualities of conventional plywood and several advantages of particular relevance to transport applications.

Durability. The chief advantage of FRP plywood panels for truck, trailer and intermodal container bodies is exceptional durability. Users report the smooth, hard-surfaced panels minimize operating costs, resist damage and wear, and deliver superior long-term performance. FRP plywood is nearly twice as strong as ordinary plywood. Field experience proves that it has excellent characteristics for the most rigorous applications, including vans operated in urban areas where narrow loading docks and streets literally nick, gouge, dent and scrape most vans into unserviceability. FRP plywood also has high resilience – it resumes its original shape after being subjected to exceptionally severe bulging loads, such as from rolls of carpeting.

Increased Cubage. FRP plywood truck, trailer and intermodal container bodies provide more usable cubage than similar metal units (4 to 7 percent more, depending on design) because no space-consuming stiffeners or intermediate framing members are required for strength. Thin-sectioned FRP panels can be produced in sizes from 4 x 8 feet to 10 x 45 feet and larger, requiring only perimeter framing. That's like adding 3 feet of length in a 40-foot trailer. FRP plywood vans and containers also are easier to load and unload because there are no projections or framing along the walls or ceiling to snag cargo or forklift masts and tines.

Easy Repair. FRP plywood vans and containers not only require less maintenance than all-metal equipment, but also simplify repairs. When traffic accidents or gross mishandling causes severe damage, repair requires only ordinary tools, skills and materials. Even a puncture can be repaired by simply cutting out the damaged section, inserting an FRP plywood plug, and resurfacing the area with fiberglass and resin – a technique much like auto body repair. Since no heat is required, temporary repairs can be made even while vans or containers are loaded.

Cargo Damage Reduction. In ordinary metal vans, the major sources of both maintenance and cargo damage reported by fleet owners are corrosion, rust and subsequent moisture leakage. Since FRP plywood is unaffected by salt and calcium chloride, corrosion and rust are eliminated. Large FRP plywood sheet size means fewer joints, and thus less damage to equipment and cargo from water leakage. In addition, plywood's favorable thermal insulation properties help prevent moisture condensation on interior surfaces, which reduces the chances of water-damaged cargos and rotting or moldy interiors.

Design Flexibility. The properties and characteristics of FRP plywood yield design freedom for equipment manufacturers and more flexible equipment for purchasers. Scuff resistance can be increased in vulnerable areas with double fiberglass overlays.

Special panels are available for drop-frame trailers. Integral flush skylights or side doors can be located almost anywhere since openings are not major structural considerations. Framing section variety also provides many options in exterior appearance and electrical wire routing.

Since interior modification of FRP plywood is simple, owners have a wide choice in installing or modifying cargo-restraint hardware, wiring, compartmentalization, racks, shelving or other accessories. Hardware and fasteners can be installed anywhere on wall or ceiling surfaces. And FRP panels accept and firmly retain a wide range of mechanical fasteners.

Aesthetic Appeal. FRP plywood vans and intermodal containers constitute moving billboards for their owners. When colored, fiberglass-reinforced plastic provides long-lasting visibility and clean lines. Corporate logos or slogans apply easily and retain their fresh appeal for years so that equipment advertises the operating firm around the clock.

Cost Advantage. The overriding reason for the proliferation of FRP plywood in the transport industry is its *long-term* cost advantage to equipment owners.

While manufacturers report that FRP plywood usually costs more than sheet metal, it also reduces manufacturing labor costs. The cost of finished FRP and metal units, therefore, is usually comparable.

Savings accrue to the user/owner in the form of greater durability, reduced maintenance requirements and improved cargo protection. When calculated on a cost-per-ton mile basis, therefore, FRP trailers and containers compare very favorably with other types of units.

Moreover, wind tunnel resistance tests have shown that smooth-sided trailers “pull” as much as 12 percent more efficiently than trailers with exposed posts.

In short, FRP units offer competitive initial cost and substantial long-term savings.

Metal Overlaid Plywood

Metal overlaid plywood panels offer advantages similar to those of FRP plywood, but their special characteristics make them particularly valuable for many transportation applications where maximum strength and durability are required. Their main use has been roll-up or swinging doors for vans. But metal overlaid plywood is also used extensively as floor and interior panels for rapid transit, passenger and baggage cars, for escalator balustrades and for slave pallets.

Depending on composite thickness and the type of overlay, metal overlaid plywood may be 10 times as strong as conventional plywood. Special panels can also be designed for demanding engineered assemblies, such as metal over fire-retardant-treated plywood core for maximum fire resistance, or lead overlays for radiation and acoustical shielding. New combinations of plywood and various metal overlays are constantly being investigated to increase cost/performance efficiency.

Foam Core Insulated Panels

Sandwich panels of fiberglass, plywood and foam have been developed for refrigerated trailer usage. While insulation is the prime requirement, foam core insulated panels must also possess high strength and unusual impact and abuse resistance.

Tests reveal that a layer of plywood under the FRP skin prevents premature breakdown of the foam core. Assuring composite action between panel elements is essential to maximize stiffness and strength.

The lightweight foam core keeps the tare weight low and provides good insulation, but is sensitive to crushing from modest surface pressure. The plywood layers sandwiching the foam core help distribute blows and concentrated pressure. Even when panels are cut or punctured, the ability of plywood to spread impact forces localizes damage.

Panel Selection

Wood structural panels can be used for floors, walls, roofs, doors or any combination of these applications in transportation equipment. In some cases a conventional panel may be the best choice; in others, a plywood panel overlaid with resin-impregnated fiber, or a panel of plywood overlaid with metal or fiberglass-reinforced plastic (FRP) may perform more satisfactorily.

The basic considerations influencing design include vehicle usage (e.g., inner-city delivery vs. long-haul); climate (corrosion resistance of framing materials, reflective roof coloring in warm climate, etc.); physical environment (rental units, fleet operation, type of loading, etc.); production facilities; and government regulations for safety and cleanliness.

Strength and stiffness of wood structural panels or structural overlaid panels are also important design considerations. This manual details the comparative strength and stiffness of bare plywood and a number of different overlays as well as approaches to applying them. While this design section presents examples of truck and trailer applications to illustrate design recommendations, most of the information also applies to intermodal containers.

Framing

Perimeter framing for trucks and containers must connect the self-supporting structural FRP plywood panels and still meet other requirements peculiar to each vehicle. Framing is often shaped to perform several functions for design simplicity. Adequate strength is basic; ease of assembly and repair, moisture resistance and appearance are also important considerations.

Figures 1-6 illustrate available frame section design options that provide durable, watertight joints. Aluminum and steel frames – and designs combining both metals – are widely used. Shapes are frequently developed for individual manufacturers, but some adapt traditional extrusion designs.

The top side rails in trailers not only connect roofs and sides, but also form a protective conduit for electrical wiring. Wiring is usually routed outside the body for easy service and modification.

Corner uprights may be designed to streamline, to improve appearance, or to efficiently integrate rear door hinges. Rear vertical framing and doors are often combined for unit assembly. Standard extrusions for truck body front corners are compatible with most overlaid plywood panels. Slots permit bolt or rivet fastening with acceptable edge distances. (See *Figure 3*.) Trailer-body builders

FIGURE 1

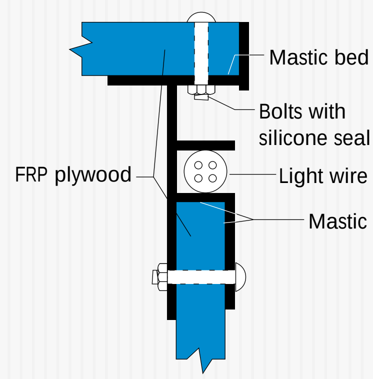


FIGURE 2

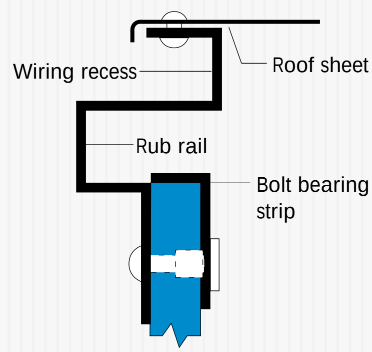
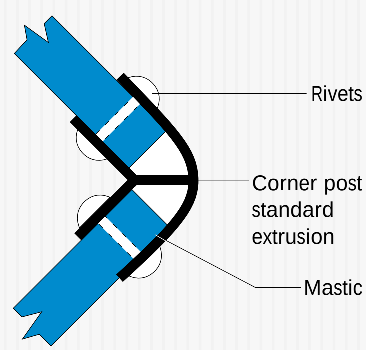


FIGURE 3



frequently use a formed metal front corner with two 45-degree angles. (See *Figure 4*.) This bevel reduces wind resistance and provides maximum inside cubage with adequate tractor clearance.

Bottom horizontal framing may be designed to connect with floor joists and function as a rub rail. Or the rub rail may be separate. (See *Figures 5 and 6*.)

Framing stiffness is discussed in detail in the section on "Fasteners," page 31. With 1/4-inch fasteners torqued to 125 in.-lb, 6 inches o.c., steel framing should be 1/8 inch thick to prevent dimpling, subsequent damage to side panels, and bowing between fasteners which can destroy the moisture seal between frame and panel. Since aluminum framing members are usually extrusions, thickness must be adequate or ribs added to prevent dimpling of fasteners into the framing. Framing and fasteners should be compatible to prevent corrosion between dissimilar materials. Rust-preventative coating for all steel and welds is highly recommended.

Joints

Design of joints between metal framing and overlaid plywood panels requires three major considerations: first, water-tightness, including frame stiffness, caulking, gasketing and fastener spacing; second, strength, which depends largely on fastener design; and third, stiffness, which influences durability and depends on fasteners and mastic.

Moisture Resistance. The face and back of FRP plywood are impervious to moisture, but panel edges are not. Manufacturers may seal edges with resin to protect against moisture absorption during assembly and handling, but even sealed edges require additional consideration for permanent protection. Unsealed panel edges must be protected from moisture absorption during assembly and handling. Final assembly design should also prevent direct moisture pickup along panel edges. Test values show a dry joint can be from 20 to 45 percent stronger than a water-soaked joint. Eliminating moisture demands careful design and early damage repair.

Both the frame and rub rail should be stiff enough to resist fastener dimpling, which can cause excessive cracking of the gel coat (if not protected by mastic) and allow moisture penetration. Dimpling can be avoided with adequate framing, by using fasteners with large enough heads or washers, or by using more fasteners to reduce clamping force per fastener.

Years of field experience with various panel-to-frame connections have proven that the double seal illustrated in *Figure 7a* is the best watertight joint.

A panel is typically bedded in mastic against the frame. An external fillet of high-performance, exposure-resistant sealant like silicon, urethane, or Thiokol is then applied along the joint between the framing edge and panel surface. This second seal precludes standing water on the edge of the framing.

FIGURE 4

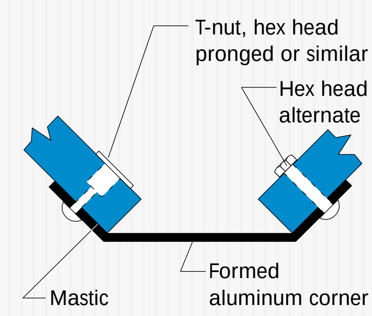


FIGURE 5

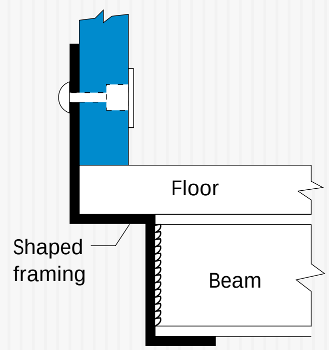


FIGURE 6

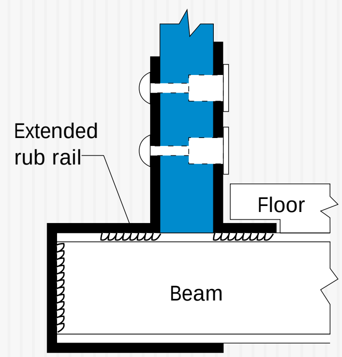
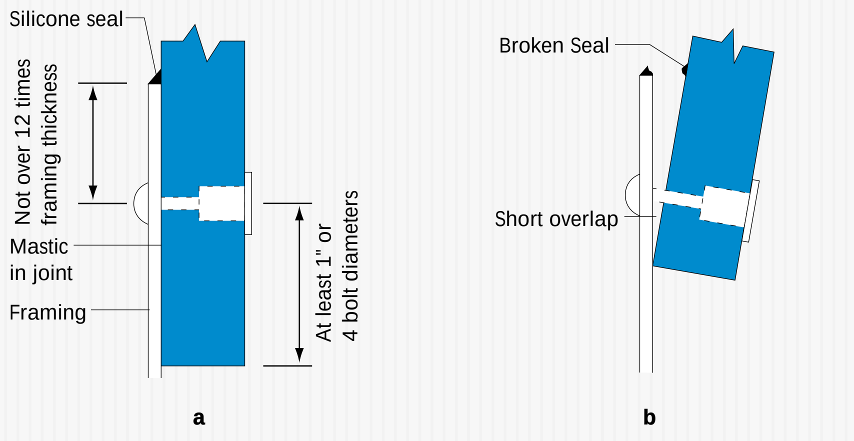


FIGURE 7



The interior mastic seal may be more precise and reliable if applied in tape form. The mastic or foam is coiled on paper in a ribbon of consistent thickness and width, and can be applied manually to assure an unbroken bead. The mastic should compress evenly and fill the joint as fasteners are tightened. This use of mastic between surfaces is dictated by watertight requirements but it may reduce joint stiffness. See section on "Fasteners" page 31.

An alternative to the two-seal caulking system shown here is a sealant-adhesive system throughout the joint. The advantages of bonding the framing to the panel (and the possibility of using fewer mechanical fasteners) must be weighed against the drawback of a material requiring mixing and gun applications.

The joint fasteners should hold the framing and the panel firmly together so panel flexing will not break the seal (*Figure 7b*). Lapping the panel over the framing three or more inches will help prevent excessive flexing between them, and an elastic sealant helps maintain the watertight seal.

Moisture drains should be provided in a fastening and sealing system so that moisture penetrating a joint has an escape route. On rare occasions, trapped moisture in a joint forms an electrolytic connection between dissimilar metals.

A close fit between bolt and bolthole increases joint stiffness. A common practice is to drill panel holes after the panel is in place using the predrilled frame holes as guides.

Fasteners. Test results on fastener strength appear at the end of this section with a discussion on their use in joint design.

Common bolts, special threaded fasteners, welded-stud bolts, non-threaded fasteners such as rivets, and pin and swaged-collar bolts are widely used in FRP plywood equipment. Self-locking fasteners counter expansion and contraction of materials as well as fastener vibration.

Pilfer-proof fasteners with smooth heads may be required, particularly in containers designed for international use. One of the most rigid fasteners of this type tested by APA is a bolt fluted to engage the metal frame. Impacted into a force-fit hole in the frame, it forms a solid connection held in place with a T-nut driven from the inside. This fastener also allows one-man tightening.

Even though fasteners are mechanically tightened, gasketing the head and nut of each one is recommended. Fasteners are available with a small recess around the underside of the head to receive a flexible washer-type gasket. All fasteners should be corrosion resistant to guard against moisture and electrolytic action between dissimilar metals.

Joint designs vary, but *Figure 8* illustrates single shear with bolts extending through rub rail, FRP plywood and steel frame. The bolts are in single shear because the rub rail is separate from the frame, and the bolt-to-frame load is carried through the joint between frame and panel only. With single-shear attachment, the panels may be drawn progressively tighter against the framework. Alignment is assured by drilling the holes after the panel is in place.

Double-shear joints *(Figure 9)* contribute significantly greater strength but assembly requirements are more complicated. Accurate alignment of the panel and rail is necessary before fastening, and working tolerance is reduced. Panel insertion may be more complicated in double-shear designs, and adequate mastic coverage can be very difficult.

Tests with both static and dynamic bolt loading prove that fastener clamping action significantly influences joint success. Clamping can be increased with greater bolt torque up to the limits of thread strength and the resistance of the frame and panel to dimpling. In some cases it may be desirable to use hardened steel bolts with higher tensile load allowances and greater shear strength. Any framing that inhibits tight clamping will reduce long-term performance of the bolted connection.

Joint slip due to cyclic loading should also be considered. There is still some question whether mastic in the joint increases such slip. Although APA static load tests showed no increase in slip with the addition of mastic, tests with cyclic loads did show significant reduction, both in ultimate load and in stiffness. But a survey of manufacturers showed no significant slip problems with the mastic. In fact, connection designs like those illustrated in *Figures 1-10* have performed satisfactorily in service with bolt spacings up to 6 inches o.c. Although mastic in the joint may reduce the capacity of a bolted connection to resist maximum-intensity cyclic load, mastic contributes to watertightness, and actual in-service loads do not seem to develop this maximum intensity.

A suggestion for determining bolt spacing involves dividing the shear load applied to that part of the connection by the allowable load per bolt. The result gives the number of fasteners required. Determination of this shear load is a matter of structural design and follows standard engineering practice.

In addition to affecting strength, fastener spacing also influences the quality of the water seal, overall stiffness, and appearance of the unit. (See *Figure 10*.) Fewer fasteners at wider spacings increase the possibility of bowing in the frame between fasteners, and of resulting weak points in the moisture seal. Moreover, larger bolts usually require heavier side rails to reduce dimpling. Successful designs have used bolt spacings from 2 to 8 inches o.c. with diameters 1/4 inch and greater. Six-inch spacing of 5/16-inch diameter bolts is common, but number of bolts may be doubled in high shear areas. Bolts are usually arranged in a single straight row or staggered in two rows.

Tests with varying edge distances (centerline of bolthole to panel edge) show that ultimate strength of the joint increases with increased edge distance. However, joint strength under dynamic loading is affected to a lesser degree in the practical range of edge distance of four bolt diameters and greater. As a rule of thumb, edge distance should be at least one inch or four bolt diameters, whichever is greater.

Static Bolt Loads. Table 6 lists APA-tested bolt loads at two slip levels and at ultimate load. It includes three different plywood core thicknesses, and a number of overlay constructions. To develop allowable design values from these test loads the designer must

FIGURE 8

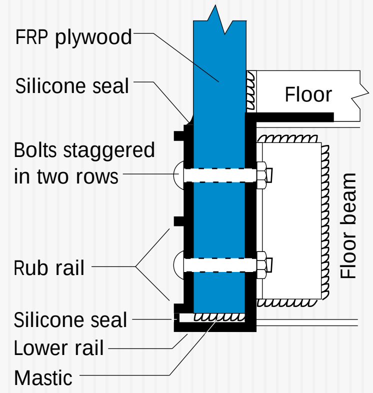


FIGURE 9

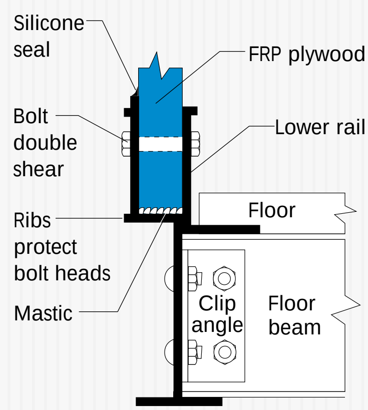


FIGURE 10

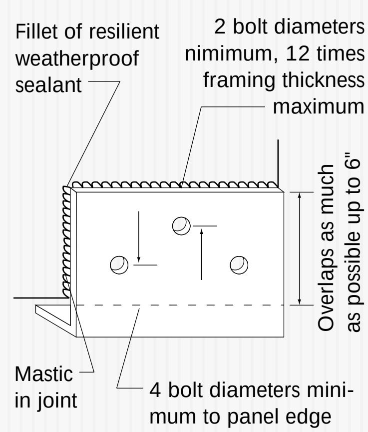


TABLE 6

STATIC BOLT LOADS (bolts and nuts finger-tight)[(a)(b)]

Overlay Description Face and Back	Bolt Diameter	Bolt Edge Distance	Single Shear 0.015" Deformation	Single Shear 0.030" Deformation	Single Shear Ultimate	Double Shear 0.015" Deformation	Double Shear 0.030" Deformation	Double Shear Ultimate
1/2" PLYWOOD CORE (APA C-D PLUGGED EXPOSURE 1 GROUP 1)								
2 oz/sq ft,	1/4"	1"	494	685	2137	943	1349	2325
chopped roving	5/16"	1-1/4"	350	630	2549	1310	1912	2818
SMC[(c)]	3/8"	1-1/2"	304	590	3158	1448	2172	3227
2.55 oz/sq ft,	1/4"	1"	437	700	2086	814	1362	2234
chopped roving	5/16"	1-1/4"	580	863	2571	1240	1996	3368
SMC[(c)]	3/8"	1-1/2"	586	958	3265	743	1652	3996
2 oz/sq ft, woven	1/4"	1"	430	756	1907	970	1362	1912
roving, wet layup	5/16"	1-1/4"	492	922	2469	840	1532	2249
(18 oz per yd)	3/8"	1-1/2"	536	995	3151	936	1935	3310
2.67 oz/sq ft, woven	1/4"	1"	460	753	2042	968	1418	2106
roving, wet layup	5/16"	1-1/4"	438	823	2435	1096	1796	2650
(24 oz per yd)	3/8"	1-1/2"	474	818	3008	1050	2014	3129
None (bare plywood)	1/4"	1"	304	491	1177	508	742	967
	5/16"	1-1/4"	292	528	1490	722	1002	1427
	3/8"	1-1/2"	492	865	1729	738	1043	1514
5/8" PLYWOOD CORE (APA C-D PLUGGED EXPOSURE 1 GROUP 1)								
2 oz/sq ft,	1/4"	1"	403	612	2112	760	1432	2391
chopped roving	5/16"	1-1/4"	473	730	2491	1273	1912	2912
SMC[(c)]	3/8"	1-1/2"	278	574	3099	1086	1988	3475
2.55 oz/sq ft,	1/4"	1"	327	608	2040	1270	1674	2286
chopped roving	5/16"	1-1/4"	566	842	2391	826	1579	2536
SMC[(c)]	3/8"	1-1/2"	312	692	3112	1410	2222	3274
2 oz/sq ft, woven	1/4"	1"	421	634	2025	974	1416	2194
roving, wet layup	5/16"	1-1/4"	518	829	2430	1271	1750	2379
(18 oz per yd)	3/8"	1-1/2"	419	654	2760	1075	1828	3045
2.67 oz/sq ft, woven	1/4"	1"	502	812	2048	915	1494	2316
roving, wet layup	5/16"	1-1/4"	400	766	2581	1030	1812	3029
(24 oz per yd)	3/8"	1-1/2"	560	956	3234	1170	1999	3108
None (bare plywood)	1/4"	1"	342	500	1195	634	926	1128
	5/16"	1-1/4"	259	426	1369	802	1044	1258
	3/8"	1-1/2"	271	594	1676	770	1196	1646
3/4" PLYWOOD CORE (APA C-D PLUGGED EXPOSURE 1 GROUP 1)								
2 oz/sq ft,	1/4"	1"	388	657	1923	883	1491	2668
chopped roving	5/16"	1-1/4"	404	688	2585	898	1603	2762
SMC[(c)]	3/8"	1-1/2"	362	825	3606	1138	2252	3765
2.55 oz/sq ft,	1/4"	1"	370	590	2258	892	1535	2516
chopped roving	5/16"	1-1/4"	600	897	2874	1224	1809	3101
SMC[(c)]	3/8"	1-1/2"	344	662	3441	1021	2074	3750
2 oz/sq ft, woven	1/4"	1"	386	731	2022	612	1396	2193
roving, wet layup	5/16"	1-1/4"	578	1004	2556	752	1438	2508
(18 oz per yd)	3/8"	1-1/2"	486	910	3150	818	1836	3150
2.67 oz/sq ft, woven	1/4"	1"	398	583	1883	796	1273	2011
roving, wet layup	5/16"	1-1/4"	437	640	2391	934	1546	2539
(24 oz per yd)	3/8"	1-1/2"	368	771	3018	1114	1984	2741
None (bare plywood)	1/4"	1"	346	528	1504	848	1151	1377
	5/16"	1-1/4"	296	560	2040	710	1220	1772
	3/8"	1-1/2"	344	715	2120	1033	1638	2328

(a) Because deformation levels in this table are small in relation to bolt-hole size tolerance of 1/32", loads at these deformation levels show some inconsistency.

(b) Bolt test load data for metal overlaid plywood is available from metal overlay fabricators.

(c) Sheet Moulding Compound (preformed glass-resin sheet cured and self-adhered to plywood core in a hot press).

anticipate use conditions. These include required unit stiffness, expected life and service severity.

Slip Designing. Since connections affect unit stiffness, designers must select the suitable value of slip, or relative movement, between panels and framing. Bolts will carry higher allowable loads if somewhat greater slip can be tolerated. The reasons for the slip levels listed in *Table 6* are:

1. A 0.015" slip is a traditional measurement for mechanically fastened wood joints.

2. A 0.030" slip is necessary to bring into bearing a bolt off-centered as far as possible in a 1/32-inch oversized hole.

3. Ultimate load is the maximum load recorded as the bolt and simulated framing were forced toward the nearest edge of the panel. Tests showed that slip at ultimate load was much greater than the listed values.

Bolt Design Values. The following formula develops numerical values for bolted joint design from the ultimate load values in *Table 6.*

The formula includes expected bolt service conditions and effects of torquing.

$DV = UL \times t \times s$

where DV = Design Value per bolt

UL = Ultimate Load value from *Table 6* for appropriate panel thickness, overlay type, bolt size, single or double shear

t = increase for torquing bolt as recommended by bolt manufacturer

s = service condition factor for equipment design

Compare the design value from the formula to the chart value for the selected deformation. This step is especially critical for single-shear connections. Sealant and mastic must be able to tolerate the movement while maintaining water-tightness.

Torque. For best joint performance, bolts should be torqued to recommended levels. Properly torquing a common Grade-2 NC bolt will improve its static load capacity about 20 percent above the finger-tight values in *Table 6.* (The test values in the chart are for finger-tight bolts because this condition was easiest to duplicate for many laboratory replications.) Clamping a correctly torqued Grade-5 NC bolt will increase static load capacity about 30 percent above finger tight. Clamping action with single-shear bolt connections may be limited by the size and strength of the nut bearing against the panel surface. Wetting and subsequent drying must be avoided to maintain the desirable clamping action of a correctly torqued bolt. (Values for joints subject to moisture absorption are about 60 percent of those for dry bolts.)

Service Condition. The service condition of a bolted connection influences the load level. Service condition comprises 1) load duration of cycle, 2) ability of design to tolerate isolated bolt distress and 3) hazard from distress. The service condition factor for use in the equation may vary from 0.50 for a routine design to 0.20 for a highly conservative design. (The factor used for structural design of a joint in a building is 0.20.)

Walls

The choice of wall panels depends on adequate strength, stiffness and durability. Since they have to do the job for the life of the unit, abuse resistance is an important consideration. While tests and experience prove that conventional plywood has adequate strength, the demand for abuse resistance, longevity and low down-time dictates the use of FRP or metal overlaid panels.

Stiffness and Strength. These are the first properties considered in evaluating any material. They indicate lateral load resistance for side panel use. The EI value in *Table 7* is a measure of panel stiffness, or deflection resistance. The “Max M” is the maximum moment, a measure of resistance to breaking under load. Stiffness is critical if the panel material is to replace both skin and posts. Comparative strength values are less critical for these applications since in practice no panel adequate for stiffness has actually failed in bending strength. As discussed earlier, other properties such as fastener-bearing strength must also be considered.

Table 7 reports results of tests on specimens large enough to accurately represent sidewall panel behavior. Specimens include panels overlaid with steel, aluminum and reinforced fiberglass by several manufacturers. The test method did not include effects of shear deflection, which in actual service may reduce effective stiffness by as much as 10 percent. Maximum moment tests conducted over 5- to 15-minute periods yielded numerical values which would have to be reduced for longer load durations. The test values indicate the range of properties available among the variety of overlaid panels. But because of the number of variables involved, these values cannot be used for exact numerical comparison.

Panels used for trailer sides are frequently 3/4-inch all-veneer APA C-D Plugged Exposure 1 overlaid on

TABLE 7

TEST DATA ON STIFFNESS AND STRENGTH OF PLYWOOD OVERLAID WITH FRP, ALUMINUM AND STEEL.

Product Description	Test Dates	Property	Plywood Core Thickness 1/2 inch Tests	1/2 inch Average	1/2 inch Range	5/8 inch Tests	5/8 inch Average	5/8 inch Range	3/4 inch Tests	3/4 inch Average	3/4 inch Range
SHEET MOULDING COMPOUND OVERLAY											
2.00 oz per sq ft chopped roving	Mar 1974	EI, lb-in^2/ft	—	—	—	4	579,600	538,800 to 625,500	4	824,300	744,100 to 890,600
		Max M, lb-in/ft	—	—	—	4	10,040	8,280 to 12,280	4	9,610	8,320 to 10,750
2.55 oz per sq ft chopped roving	Mar 1974	EI, lb-in^2/ft	—	—	—	4	710,500	654,000 to 754,700	4	988,400	831,700 to 1,131,900
		Max M, lb-in/ft	—	—	—	4	11,400	9,750 to 12,470	4	11,080	10,080 to 11,840
WOVEN ROVING OVERLAY (WET LAYUP)											
2 oz per sq ft glass (18 oz per sq yd) PS 1 Group 1 plywood	Jan 1969 thru May 1970	EI, lb-in^2/ft	2	262,600	258,500 to 266,600	2	497,600	490,300 to 505,500	3	950,000	831,700 to 1,013,300
		Max M, lb-in/ft	2	6,730	6,070 to 7,390	2	8,960	8,360 to 9,560	3	13,160	12,440 to 13,900
2.67 oz per sq ft glass (24 oz per sq yd) PS 1 Group 1 plywood	May 1966 thru Mar 1971	EI, lb-in^2/ft	—	—	—	3	587,460	563,100 to 608,300	20	916,500	768,000 to 1,100,400
		Max M, lb-in/ft	—	—	—	3	11,240	10,350 to 12,830	20	12,800	10,100 to 18,350
2.67 oz per sq ft glass (24 oz per sq yd) PS 1 plywood, group undetermined	Apr 1969 thru Feb 1971	EI, lb-in^2/ft	—	—	—	1	352,000	—	10	913,100	787,000 to 1,053,300
		Max M, lb-in/ft	—	—	—	1	6,170	—	10	12,160	10,330 to 13,250
ALUMINUM SHEET OVERLAY											
25-mil aluminum PS 1 Group 1 plywood	Jan 1970	EI, lb-in^2/ft	1	713,600	—	—	—	—	2	1,577,800	1,542,800 to 1,612,700
		Max M, lb-in/ft	1	5,980	—	—	—	—	2	11,670	11,340 to 12,000
40-mil aluminum PS 1 Group 1 plywood	Jan 1970	EI, lb-in^2/ft	1	1,004,500	—	—	—	—	2	2,325,800	2,281,100 to 2,370,600
		Max M, lb-in/ft	1	9,870	—	—	—	—	2	15,810	15,660 to 15,960
GALVANIZED SHEET STEEL OVERLAY											
28-gauge steel PS 1 Group 1 plywood	Apr 1969 thru Apr 1970	EI, lb-in^2/ft	6	1,054,500	985,200 to 1,106,800	2	1,539,600	1,502,100 to 1,577,000	—	—	—
		Max M, lb-in/ft	6	8,400	6,990 to 9,720	2	10,990	10,520 to 11,460	—	—	—
26-gauge steel PS 1 Group 1 plywood	Apr 1970 thru July 1970	EI, lb-in^2/ft	2	1,180,700	1,179,300 to 1,182,100	2	1,712,800	1,673,700 to 1,752,000	—	—	—
		Max M, lb-in/ft	4	8,760	7,270 to 9,310	2	12,100	11,950 to 12,240	—	—	—
22-gauge steel PS 1 Group 1 plywood	Apr 1969	EI, lb-in^2/ft	4	1,963,900	1,664,100 to 2,200,800	—	—	—	—	—	—
		Max M, lb-in/ft	4	12,520	11,190 to 13,450	—	—	—	—	—	—

TABLE 8

FORK-TINE DAMAGE RESISTANCE OF SELECTED FRP PLYWOOD CONSTRUCTIONS

Plywood Core Thickness	Overlay Description – face and back	Resistance of Composite (% of 3/4" bare plywood)
1/2"	2 oz per sq ft chopped roving SMC	280
	2.55 oz per sq ft chopped roving SMC	330
	2 oz per sq ft (18 oz per yd) woven roving	340
	2.67 oz per sq ft (24 oz per yd) woven roving	400
	None (bare plywood)	70
5/8"	2 oz per sq ft chopped roving SMC	340
	2.55 oz per sq ft chopped roving SMC	420
	2 oz per sq ft (18 oz per yd) woven roving	440
	2.67 oz per sq ft (24 oz per yd) woven roving	560
	None (bare plywood)	80
3/4"	2 oz per sq ft chopped roving SMC	430
	2.55 oz per sq ft chopped roving SMC	500
	2 oz per sq ft (18 oz per yd) woven roving	540
	2.67 oz per sq ft (24 oz per yd) woven roving	670
	None (bare plywood)	100
18 gauge corrugated steel	U.S. Army Conex Container	300

both surfaces with 2.67 or 2.55 ounces of glass per square foot. Truck sides are often 5/8-inch-core panels. Varying combinations of plywood core thicknesses, core species, and glass content provide panels with the strength, stiffness and abuse resistance essential for specific design and usage. Manufacturers can provide information on engineering properties and costs of available structural overlays.

Fork-Tine Resistance. Table 8 not only illustrates panel resistance to direct fork-tine puncture, but also roughly charts general abuse resistance. Case histories have confirmed these laboratory findings: structural overlaid plywood panels survive severe accidents and require only cosmetic surface repairs.

Tree limb impact resistance can be measured by the same table because loads relate to those imposed in the tine impact test. The values also indirectly measure resistance of various structural overlaid panels to scuffing during van loading and unloading. Laminators offer panels with integral scuff strips (a double glass application on the lower portion of a panel's inside surface) for van interiors expected to sustain high wear.

Front-End Strength and Penetration Resistance. Testing has confirmed that all common structural overlaid panels used for truck and trailer front ends easily meet the strength and penetration resistance requirements established by the U.S. Bureau of Motor Carrier Safety in Regulation MC-12.

Since the typical 3/4-inch panels used for trailer front ends survived the test loading without visible damage, they also fulfill the requirements for piggy-back service.

The tested load level was unusually severe – higher than that currently required by any state highway department. Well-manufactured, carefully detailed panels are required for such severe loadings. For lighter cargos and correspondingly reduced front-end loads, thinner-cored panels are more than adequate.

U.S. Department of Transportation BMCS Regulation MC-12 requires that truck and trailer front-end structures over six feet high withstand 4/10 of the cargo weight, uniformly distributed. For a trailer rated at 60,000-pound capacity, this force totals 24,000 pounds.

The regulation also stipulates that the structure must resist penetration by any adjacent cargo item when decelerated at 20 feet per second per second. This regulation and truck loading practice suggested checking two critical conditions: first, panel resistance to penetration by a 1-inch bar 40 feet long, decelerated according to MC-12 specification. Thirty-seven-pound resistance satisfies this requirement. Second, a 289-pound penetration resistance has been determined to adequately restrain a bundle of seven 1-inch pipes 40 feet long.

All tested panels were routinely produced by FRP plywood manufacturers. They had either 2.55 oz. per square foot of chopped-roving sheet-molding compound, or 2.67 oz. per square foot (24 oz. per square yard) of woven roving, on plywood core panels of 3/4-inch, 5/8-inch, or 1/2-inch thickness. They were tested in a trailer nose 7 feet wide and 9 feet high (panel size 82 x 100 inches). All withstood 24,000 pounds of uniformly distributed load. The 1/2-inch and 5/8-inch panels, in some cases, showed surface resin cracking and required minor cosmetic repair. The 3/4-inch panels sustained no visible damage. All displayed ultimate puncture resistance in excess of 1700 pounds (load factor equals 46) for a 3/4-inch-diameter rod, and over 5,000 pounds (load factor equals 17) for a bundle of seven 1-inch pipes.

Doors

Door Framing. Since most truck, trailer and container side doors are shorter than unit height, part of the overlaid panel remains to span the opening and carry the load. Trailer bodies may require additional support over the opening – usually a bolted metal header plate extending about a foot beyond the opening. This extra plate isn't necessary in most truck bodies because the underframe carries the load. In either case the door may be made of material cut from the opening.

Conventional side-door hinges and locking bars work well with overlaid plywood. Watertight seals around door openings are critical. (See illustrations and comments on joints on pages 10-11.)

Rear doors may be any common design, either hinged or roll-up. These doors are usually metal-overlaid plywood panels or Medium Density Overlaid plywood with a paint finish.

Most rear-door corner posts are tubular metal. Door headers are welded to these uprights, occasionally gusseted at each corner with fillet plates for extra rigidity. Side panels fit into lips on the posts.

Door Construction. Designs for metal-overlaid plywood doors vary from structural assemblies in intermodal containers (where door tests include direct loadings as high as 25,000 pounds and racking loads of 35,000 pounds) to relatively light curbside truck doors which need contribute little to the unit's structural capabilities. But even for the lightest applications, overlaid plywood panels are generally specified because of their weather durability and resistance to damage under punishing use.

Manufacturers offer several edge treatments for different hardware and gasket attachment systems. Where edges are exposed to abrasion or impact, a rolled or locked edge is recommended. This edge mechanically locks the metal faces together for a smooth gasket surface. The joint is not waterproof, but it sheds water well enough to use for vertical edges. A whole spectrum of rubber and plastic gaskets offers options to locked metal edges. Gasket detail and door blank size should be carefully considered in designing a good seal.

The bottom edge is the most vulnerable section of most doors. It's exposed to severe wear, and may trap moisture which can corrode the backs of metal surfaces. A high-quality, factory-installed bottom seal is the best insurance against this kind of water damage.

Floors

Tables 9 and 10 aid selection of correct plywood for floors which must support wheel loads – fork lifts, for instance. Wheel loadings are normally much more critical than uniform loads in plywood floor design. For example, a grain truck has a uniformly loaded floor. If the 50 pcf grain were piled 5 feet high, the uniform load would equal 250 psf. In *Table 9* with framing spaced 24 inches o.c., a Rated Sturd-I-Floor 48 oc (2-4-1) plywood floor is recommended. APA 2-4-1 EXPOSURE 1 (1-1/8 inches thick) has been used in many truck bodies and trailers where forklift wheel loadings were not anticipated or were relatively light.

TABLE 9

PS 1 PLYWOOD RECOMMENDATIONS FOR UNIFORMLY LOADED HEAVY DUTY FLOORS[(a)]
(Deflection limited to 1/240 of span.)
(Span Ratings apply to APA RATED SHEATHING and APA RATED STURD-I-FLOOR, respectively, marked PS 1.)

Uniform Live Load (psf)	Center-to-Center Support Spacing (inches) (Nominal 2-inch-width supports unless noted)					
	12[(b)]	16[(b)]	20[(b)]	24[(b)]	32	48[(c)]
50	32/16, 16 oc	32/16, 16 oc	40/20, 20 oc	48/24, 24 oc	48 oc	48 oc
100	32/16, 16 oc	32/16, 16 oc	40/20, 20 oc	48/24, 24 oc	48 oc	1-1/2[(d)]
150	32/16, 16 oc	32/16, 16 oc	40/20, 20 oc	48/24, 48 oc	48 oc	1-3/4[(e)], 2[(d)]
200	32/16, 16 oc	40/20, 20 oc	40/20, 24 oc	48 oc	1-1/8[(e)], 1-3/8[(d)]	2[(e)], 2-1/2[(d)]
250	32/16, 16 oc	40/20, 24 oc	48/24, 48 oc	48 oc	1-3/8[(e)], 1-1/2[(d)]	2-1/4[(e)]
300	32/16, 16 oc	48/24, 24 oc	48 oc	48 oc	1-1/2[(e)], 1-5/8[(d)]	2-1/4[(e)]
350	40/20, 20 oc	48/24, 48 oc	48 oc	1-1/8[(e)], 1-3/8[(d)]	1-1/2[(d)], 2[(d)]	—
400	40/20, 20 oc	48 oc	48 oc	1-1/4[(e)], 1-3/8[(d)]	1-5/8[(e)], 2[(d)]	—
450	40/20, 24 oc	48 oc	48 oc	1-3/8[(e)], 1-1/2[(d)]	2[(e)], 2-1/4[(d)]	—
500	48/24, 24 oc	48 oc	48 oc	1-1/2[(d)]	2[(e)], 2-1/4[(d)]	—

(a) Use plywood with T&G edges, or provide structural blocking at panel edges, or install a separate underlayment.
(b) A-C Group 1 sanded plywood panels may be substituted for Span Rated Sturd-I-Floor panels (1/2-inch for 16 oc; 5/8-inch for 20 oc; 3/4-inch for 24 oc).
(c) Nominal 4-inch wide supports.
(d) Group 1 face and back, any species inner plies, sanded or unsanded single layer.
(e) All Group 1 or Structural I plywood, sanded or unsanded, single layer.

TABLE 10

PS 1 PLYWOOD RECOMMENDATIONS FOR FLOORS CARRYING FORK-TRUCK TRAFFIC[(a)(b)(c)]
(Plywood grade is all-Group 1 or Structural I A-C or C-C Plugged, except where 2-4-1 [STURD-I-FLOOR 48 oc marked PS 1] is noted.)

Tire Tread Print Width (in.)	Load per Wheel (lbs.)	Center-to-Center Support Spacing (in.) (Minimum 3-inch-wide supports)			
		12	16	20	24
3	500	2-4-1	2-4-1	2-4-1	2-4-1
	1000	1-1/4"	1-1/4"	1-1/4"	1-1/4"
	1500	1-1/2"	1-3/4"	1-3/4"	1-3/4"
	2000	2"	2"	2-1/4"	2-1/4"
5	1000	2-4-1	2-4-1	1-1/8"	1-1/8"
	1500	1-1/8"	1-1/8"	1-1/4"	1-1/4"
	2000	1-1/4"	1-1/2"	1-1/2"	1-3/4"
	2500	1-1/2"	2"	2"	2"
	3000	1-3/4"	2"	2-1/4"	2-1/4"
7	2000	1-1/8"	1-1/8"	1-1/4"	1-1/4"
	3000	1-1/4"	1-1/2"	1-1/2"	1-3/4"
	4000	1-3/4"	1-3/4"	1-3/4"	2"
	5000	2"	2"	2-1/4"	2-1/2"
	6000	2-1/4"	2-1/2"	2-3/4"	3"
9	3000	1-1/4"	1-1/4"	1-1/4"	1-1/4"
	4000	1-1/2"	1-1/2"	1-3/4"	1-3/4"
	5000	1-3/4"	1-3/4"	2"	2"
	6000	2"	2"	2-1/4"	2-1/4"
	7000	2-1/4"	2-1/4"	2-3/4"	2-3/4"

(a) Structural blocking (3x4 or 2x6 min.) required at all panel edges. Support blocking with framing anchors of adequate capacity or similar devices.
(b) Provide a wearing surface such as Plyron, polyethylene or a separate layer of plywood, hardboard or other hard surface when loads are due to casters, or small, hard wheels. A wearing surface should also be considered for areas where fork-truck traffic is stopping, starting or turning in a tight radius.
(c) Use ring- or screw-shank nails with length sufficient to penetrate framing 1-1/2" or panel thickness, whichever is greater. Space nails maximum 4" o.c. at panel edges and 8" o.c. at interior supports.

Table 10 recommends plywood floor systems for moderate concentrated loads from forklift traffic. It lists plywood thicknesses for various wheel loads and spans based on APA tests. The table shows loads at 65 percent or less of the lowest tested distress load.

Roofs

Panel requirements for truck or trailer roofs vary slightly from side walls since loadings differ. The most severe roof loadings are snow, ice and standing workmen. Most roofs have been made of APA C-D PLUGGED Exposure 1 Group 1 plywood, 1/2 inch thick, with 2 oz. per square foot (18 oz. per square yard) glass content FRP on both faces. Users report that this roof will permit workmen on the roof to maintain upper corner lighting, shrugs off blows and scrapes from tree limbs and sustains less damage from forklift masts. If the roof is struck by a mast raised too high, it's resilient enough to spring back to normal.

Plywood roof panels require no roof bows. Roof panels are bedded in mastic along the upper side rails, then fastened with mechanical connections, usually bolts. Take care to achieve a secure, watertight seal between panel and frame and at bolt connections – either with gaskets or neoprene washers under boltheads and nuts, or with a high-performance sealant such as silicone over each bolthead and nut.

Sheet aluminum roofs on bows also are compatible with vans sided with structural overlaid plywood. Such roofs decrease overall weight slightly, but lack the superior strength and puncture resistance that overlaid plywood roofs deliver.

Cargo Restraint Devices

Logistic Track. With spaced fasteners, ultimate track attachment strength depends largely on the stiffness of the track itself. The track must be rigid enough to transmit loads to many fasteners over a wide area.

Sheet Metal Screws. Sheet metal screws are the most popular fasteners for logistic track because they are easily driven, relatively inexpensive and perform well. Long sheet metal screws driven at a 45-degree angle yield significantly better results than shorter screws driven straight. Most track provides a corner or angled area through which 45-degree angle holes can be easily drilled. One-and-one-quarter-inch-long screws are easy to handle and develop few stripping problems.

Bolts. Bolts are strong, simple and positive, but outside heads or capped T-nuts are unsightly and a source of potential leaks. Sealants and noncorrosive heads are essential. An extra rub rail outside, under bolt heads, increases allowable track loading.

Gasketing of Fasteners. Gaskets, neoprene washers, or any other effective method of achieving a watertight seal at fastener penetrations, both inside and outside of the container, are strongly recommended.

Adhesives. Adhesives supplement, but do not replace, mechanical fastenings for logistic track. Cleanliness of unpainted track, paint adhesion, adequate contact, proper curing and proper surface preparation must be considered in designs incorporating adhesives. While even a good bond may separate surface resin from fiberglass in a coated panel, flexible-bond adhesives combined with proven fastener patterns yield superior performance.

Recessed D-rings. According to APA tests, a combination of adhesive and mechanical fasteners works best with recessed D-rings. Two screws usually were not sufficient to develop satisfactory withdrawal resistance. Adhesives increase strength, seal panel surfaces and help hold rings in place. As with track hardware, the best adhesive results are obtained with the largest contact area between hardware and panel.

Fastener Strength. Table 11 illustrates ultimate loads developed from laboratory test data for several fasteners with four load-restraint devices. The tested number of fasteners may not have been identical to that suggested in the table. The number of fasteners per foot is a practical optimum. Reducing the number may be possible where anticipated loads are less. Increasing the number will increase the load, but not necessarily in proportion to the number of added fasteners.

Note that withdrawal loads over 4,000 pounds and vertical loads over 8,000 pounds on the belt rails are beyond the practical load range of the devices applying the load to the track. These values are only included for comparison.

FRP Plywood Fabrication and Repair

Cutting. Use a sabre saw for cutting small holes and oddly shaped openings. Use a medium-fine-toothed, hardened-steel blade, and, to lengthen blade life, avoid forcing the rate of cut. For longer cuts (24 inches or more) use a hand-held power saw with an industrial quality, carbide-tipped blade. Expose only as much blade as required for teeth gullets to clear the panel and release sawdust.

TABLE 11

LOAD RESTRAINT FASTENING STRENGTH

Fasteners*	Logistic Track (Belt rail) Aeroquip Series E	Logistic Track (Belt rail) Evans Slimline or S-Type	Logistic Track (Belt rail) Evans Special S-Type	Recessed Rope Ring Eberhard No. 170
SCREWS 3/4" x No. 14 Sheet metal (12 per ft of track 2 per rope ring)	3,300 lbs withdrawal 14,000 lbs vertical	2,450 lbs withdrawal 10,500 lbs vertical	2,900 lbs withdrawal 12,300 lbs vertical	400 lbs withdrawal —
BOLTS – 1/4"-20 with capped T-nut (4 per ft of track 2 per rope ring)	7,300 lbs withdrawal 6,900 lbs vertical	5,500 lbs withdrawal 5,200 lbs vertical	6,400 lbs withdrawal 6,100 lbs vertical	1,600 lbs withdrawal —
BLIND INSERTS Helicoil–1/4"-20 5/8" long 2885-4AQ or Rosan 1/4"-20 1/2" long RNS 106 SB-8 (12 per ft of track 2 per rope ring)	5,200 lbs withdrawal 19,000 lbs vertical	3,900 lbs withdrawal 14,000 lbs vertical	5,100 lbs withdrawal 16,500 lbs vertical	620 lbs withdrawal —
ADHESIVES Flexible 2-part epoxy or Flexible 2-part urethane or Polysulfide rubber-epoxy–2-part Full contact coverage Plus 2 screws per ft for assembly	1,300 lbs withdrawal 10,000 lbs vertical	750 lbs withdrawal 3,200 lbs vertical	1,950 lbs withdrawal 9,000 lbs vertical	1,060 lbs withdrawal —

*Panel is 23/32-inch APA C-D Plugged Exposure 1, all plies Group 1, with 18 oz/yd woven roving FRP.

For full-panel cuts, laminators use special saws mounted on heavy steel frames to assure clean, true cutlines. The blades, which have high-quality carbide tips, may be 14 inches or more in diameter. Where possible, major panel cutting and trimming should be done by the panel manufacturer to assure accurate cuts.

Drilling. Sharp bits operated at high speed (1500 rpm or more) with moderate feed assure clean holes with maximum bolt bearing. Since a significant amount of bolt strength comes from the FRP overlay, a clean-cut hole with a minimum of torn or chipped glass and resin is essential.

Note: Workers cutting or drilling FRP plywood should wear dust masks. Persons allergic to fine glass dust should protect arms, necks and hands.

Repair. In service, FRP plywood resists both abrasion and impact damage. Experience has shown it to be simple to repair, even after severe accidents.

Appearance and unit life determine whether a simple cosmetic patch or restoration of strength (as well as surface) is required. Re-sealing the surface is primary, but strength loss always must be evaluated. If glass fibers are cut or fractured, fiber patches should be used. Less severe damage can usually be repaired with body putty or resin and glass cloth.

For additional information on repair procedures, consult panel suppliers or write for APA's *Data File: FRP Plywood*, Form G215.

Metal Overlaid Plywood Fabrication

Cutting. Manufacturers of plywood/metal panel products report best results with a hard-edge, 10-tooth, 5/8-inch by 20 gauge, wavy set, metal-cutting band-saw blade operating at from 300 to 3000 feet per minute. Fair results are reported with standard woodworking tools on soft metal overlays such as aluminum, lead and copper. Panels with metal on one side only should be cut with the metal side up.

Drilling. Use carbon-steel twist drills. High-speed bits wear longer and cut cleaner. Extension cutters or metal-cutting hole saws can be used for larger-diameter cuts.

Note: Where practical, cutting, shaping and routing of plywood/metal overlays should be done by the panel manufacturer. Most manufacturers provide cut-to-size service and instructions for working their products with welding, routing, soldering and shaping equipment.

TRUCK, TRAILER & RAIL CAR LININGS

Because of their inherent strength, durability and smoothness, conventional wood structural panels and structural overlaid plywood panels provide excellent lining materials for trucks, trailers, vans and rail cars. Since linings are ordinarily subjected to extremely rough usage, many factors govern material selection. The following recommendations are based on both laboratory testing and broad field experience. They may be used as presented for design development, or regarded as a basis for comparison with other lining materials.

Panel Selection

Unless specific or unusual use requirements are anticipated, specify 1/4-inch plywood or 3/8-inch APA trademarked wood structural panels for truck side linings. The most popular thickness is 1/4 inch. For front-end linings that meet DOT requirements (discussed in the following section), specify 1/2-inch APA trademarked Group 1 plywood. Heavier bulkheads are usually recommended in intermodal or piggyback van front wall construction, usually 5/8- or 3/4-inch plywood. For railroad car linings use 1/2-inch or 5/8-inch plywood for sides, 1 or 1-1/4 inch for ends.

For smooth interior surfaces, specify APA A-C EXTERIOR plywood. This panel is intended for use in the most severe exposure conditions. For less exacting applications, APA A-D EXPOSURE 1 or C-D PLUGGED EXPOSURE 1 may be used. The trademarks shown here are those stamped on plywood most commonly used as liner material.

Truck And Trailer Front-End Structures

The Department of Transportation has established front-end-structure requirements as "Protection Against Shifting or Falling Cargo" for all new cargo-carrying vehicles.

DOT Requirements. If the front-end structure is less than 6 feet high, the DOT says it must withstand a forward static load equal to 0.5 cargo weight distributed over the lower 4 feet of the end wall. If the end wall is higher than 6 feet, it must withstand a forward static load equal to 0.4 cargo weight distributed over the entire end structure. The structure must also resist penetration at a deceleration rate of 20 feet per second per second.

These requirements are not substantially different from industry standards. The Truck Trailer Manufacturers Association (TTMA) Recommended Practice No. 17 suggests for trailers on flat cars (piggyback) a load equal to 0.32 to 0.36 cargo weight depending on the number of axles for the trailer, but has a permanent residual deformation that could inhibit the function of the unit (assumed to be 1/2 inch or less).

Since the DOT Motor Carrier Safety Regulations apply to all vehicles – not just the van type – the use of plywood as a front bulkhead on other types of trailers and trucks helps meet the requirements. Many states have individual requirements for bulkheads or front-end structures in trucks. One state, for example, specifically mentions 3/4-inch plywood as a front bulkhead material.

Compliance. Experience and tests show that truck or trailer front wall lining of 1/2-inch APA trademarked plywood of Group 1 woods can meet the front-end strength requirements without structural change to the trailer, if the boundary framework is adequate and the plywood well fastened to the framework.

Recognizing that trailer owners might wish to strengthen the front ends of their existing trailers to the same level required for new equipment, APA tested several possible means of achieving this end. These tests demonstrated that equipment built prior to January 1,

TYPICAL APA TRADEMARKS

APA
THE ENGINEERED WOOD ASSOCIATION
A-D GROUP 1
EXPOSURE 1
000
PS 1-95

APA
THE ENGINEERED WOOD ASSOCIATION
A-C GROUP 1
EXTERIOR
000
PS 1-95

APA
THE ENGINEERED WOOD ASSOCIATION
C-D PLUGGED
GROUP 1
EXPOSURE 1
000
PS 1-95

1974 can be retrofitted to meet the strength and penetration requirements by (1) applying 1/2-inch plywood over the existing 1/4-inch lining, or (2) removing the 1/4-inch lining if damaged and replacing with 1/2-inch plywood lining.

The 1/2-inch plywood, used instead of 1/4 inch, may not suffice for all designs since not all designs were tested. However, the tests show that thicker linings are beneficial regardless of the structural design of the trailer.

APA Front-End Testing. A joint test by *APA – The Engineered Wood Association* and Timpte, Incorporated, Denver, Colorado, demonstrated clearly that plywood truck trailer linings thicker than the 1/4-inch lining normally used contributed substantially to the stiffness of the front-end structure and the unit's ability to meet DOT strength requirements. The test program used the normal nose structure of the dry van trailer, modifying only the inside nose lining and its fastenings.

General conclusions are:

New Designs:

1. The DOT strength requirement was fulfilled in the tests with 1/2-inch plywood as the nose lining.

2. Thicker and stiffer plywood linings reduce the stress in the aluminum structure and skin for a given load pressing against the inside.

3. Increasing the nose lining thickness to 1/2 inch substantially stiffens the front end so that the full perimeter of the nose restrains the load.

Retrofitting:

1. Applying 1/2-inch plywood over the existing nose lining of 1/4-inch plywood will strengthen it adequately to fulfill the DOT requirements.

2. Replacing the nose lining with 1/2-inch plywood as previously mentioned in New Design (1) can enable it to meet the requirements.

Test Unit Description. The trailer tested was a 40-foot-long dry van trailer, 13 feet 4 inches high, as normally produced by Timpte, Incorporated. Although trailers from various manufacturers vary considerably, this one was typical of better construction in the industry. The nose structure had 10-inch radius corners. Nose skin was 0.050-inch aluminum applied over 1-3/4-inch Z posts. Six Z posts were used in the nose structure. Both the skin and posts bear against the inside surface of the upper nose rail and the coupler assembly.

Test Procedure. Load was applied to the inside of the nose assembly through 16 uniformly spaced hydraulic jacks bearing against 1-foot-square plywood load-distributing pads to simulate cargo bearing uniformly against the front structure.

The first stage of loading achieved approximately 2 inches of deflection at the midpoint of the center post of the front-end structure. This condition would cause little, if any, permanent set in the front-end structure when unloaded. Previous tests with the Z posts had established this point as closely approximating the yield point for the framework.

The second stage of loading achieved either a failure condition or a condition in which failure of a portion of the nose not readily reparable was imminent. Deflection of the front-end structure was measured at six points, stress in the aluminum structure at ten points, and movement at joints at eight points.

Results. Table 12 shows the stiffening effect of thicker plywood lining, evidenced by the higher load capability at a uniform deflection of 2 inches. Although not shown, the stress of the aluminum structure decreased in correspondence with the increase in load at the 2-inch deflection. All of the maximum loads shown exceed the criterion of 0.4 of an assumed cargo weight of 55,000 pounds. Thus, either the use of 1/2-inch APA trademarked A-C plywood over the Z posts, or the addition of 1/2-inch plywood over an existing 1/4-inch lining meets the DOT requirements for the test trailer. For vans with greater cargo capacity rating, thicker plywood can be used or the adhesive bonding of the plywood to the posts can achieve higher loadings. Extending the nose lining plywood into the curved corner and using aluminum flashing helps hold the curved shape. (See details page 23.)

Panel Installation

Orientation and Framing. Wood structural panels are strongest, and possess the greatest deflection resistance, when installed with the long dimension or strength axis perpendicular to framing.

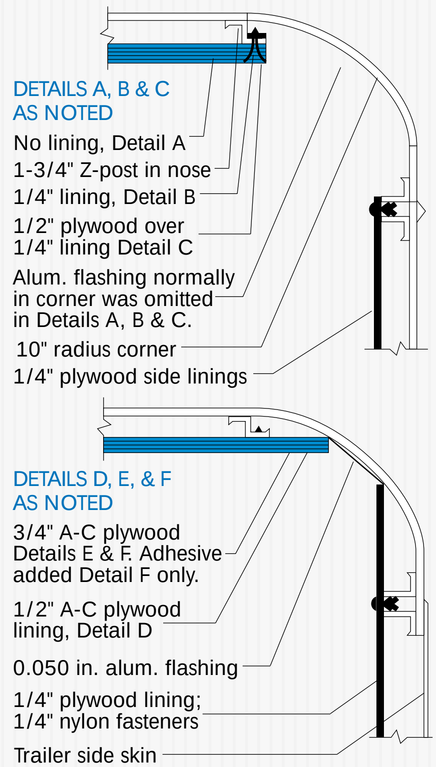
Depending on panel orientation and use, edge blocking may be necessary. Panels installed horizontally (strong axis perpendicular to wall posts) should be

TABLE 12

TEST RESULTS

Trailer Lining	Detail	Test for 2-in. Deflection	Test for Maximum Loading		
		Load (lb)	Load (lb)	Why Terminated	Deflection (in.)
None	A	7,000	—	—	—
1/4-in. A-C plywood 1/4-in. nylon fasteners 12 in. oc	B	7,767*	—	—	—
1/2-in. A-C plywood over the construction above 1/4-in. deck screws 6 in. oc	C	11,765*	22,200	skin corner tore	3.70
1/2-in. A-C plywood 1/4-in. deck screws 10 in. oc	D	11,082*	27,973	stopped to preserve upper nose rail	3.35
3/4-in. A-C plywood 1/4-in. deck screws 10 in. oc	E	12,503*	31,225	stopped to preserve upper nose rail	3.50
3/4-in. A-C plywood Screws 10 in. oc and adhesive bonded to posts	F	15,385*	31,524	stopped to preserve upper nose rail	3.51

*Interpolated from readings for deflections ranging from 2.04 in. to 2.08 in.



blocked to ensure a smooth joint and permit tight sealing of insulated walls. Panels installed vertically (strong axis parallel to wall posts) should be blocked along lower edges to reduce wear due to handling-equipment scuffing. Metal or plywood scuff plates that can be easily replaced as wear occurs are also recommended.

Panels should be spaced 1/8 inch at all joints to allow for possible expansion.

Joint Treatment and Sealing. In refrigerated equipment, moisture exclusion is essential to preserve materials and promote thermal efficiency of insulation.

Joint moldings and sealers are always recommended for refrigerated vans with plywood linings. Plywood linings should also be sealed to prevent moisture migration through panels. Dip-sealing ensures that both panel sides and edges are thoroughly sealed. (Only approved nontoxic sealers are permitted in equipment used to haul foodstuffs.)

Overlaid or coated plywood products such as High Density Overlay minimize joints and provide a positive vapor barrier. Fiberglass-reinforced-plastic plywood panels are available in sizes large enough to cover the entire wall of a 45-foot van. Such panels are particularly useful where frequent cleaning is required and where a complete moisture seal is mandatory.

Fastener Selection. Many kinds of fasteners are suitable for securing panel linings to trailers or rail cars. Fastener selection depends upon these basic factors:

Strength – strength sufficient to resist withdrawal and lateral loads is required. Such loads are not usually severe, but can increase dramatically if cargo restraint devices, hooks, shelving or other loads are imposed on the lining. A large fastener shank will sustain the highest shear load. Front-end strengthening sometimes requires more fasteners than simple attachment.

Contour – the heads of fasteners should be flush – or nearly flush – with the lining to minimize snagging and cargo damage. A large-diameter, low-profile head fulfills this requirement.

Removal – fasteners should be easily removable for repair or panel replacement. Some fasteners must be sheared or ground down for removal at substantial cost in labor and materials.

Compatibility – fasteners should be compatible with intended loads and use conditions. For example, plastic or stainless steel fasteners may be required for certain kinds of food cargo. Fasteners that resist moisture may be required where high environmental moisture will be encountered.

TABLE 13

SHEET METAL SCREWS: PLYWOOD-TO-METAL CONNECTIONS[a]

Framing	Plywood Thickness (in.)	Ultimate Lateral Load (lb)[b] Screw Size #8	#10	#12	#14	1/4"-20 Self Tapping Screw
0.080" Aluminum	1/4	330	360	390	410	590
	1/2	630	850*	860	920	970
	3/4	910*	930*	1250	1330	1440
0.078" Galvanized Steel (14 gauge)	1/4	360	380	400	410	650
	1/2	700*	890*	900	920	970
	3/4	700*	950*	1300*	1390*	1500

(a) Plywood was A-C EXT grade (all plies Group 1), face grain parallel to load.

(b) Loads denoted by an asterisk (*) were limited by screw-to-framing strength; others were limited by plywood strength.

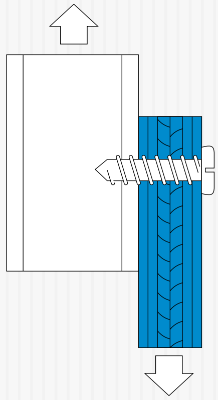


TABLE 14

SHEET METAL SCREWS: PLYWOOD-TO-METAL CONNECTIONS[a]

Framing	Plywood Thickness (in.)	Ultimate Withdrawal Load (lb)[b] Screw Size #8	#10	#12	#14	1/4"-20 Self Tapping Screw
0.080" Aluminum	1/4	130	150	170	180	220
	1/2	350	470	500	520	500
	3/4	660	680	790	850*	790*
0.078" Galvanized Steel (14 gauge)	1/4	130	150	170	180	220
	1/2	350	470	500	520	500
	3/4	660	680	800	900	850

(a) Plywood was A-C EXT grade (all plies Group 1).

(b) Loads denoted by an asterisk (*) were limited by screw-to-framing strength; others were limited by plywood strength.

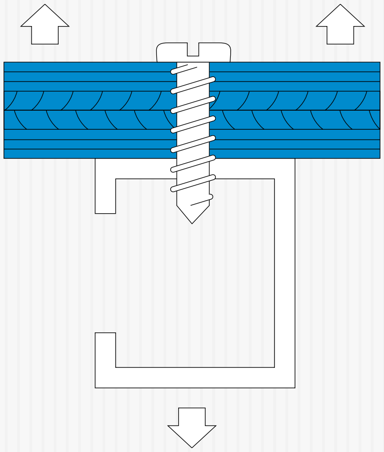


TABLE 15

FASTENER EQUIVALENCY
1/4-in. A-C Plywood Lining

Fastener	Body Diameter (in.)	Head Diameter (in.)	Equivalent Sheet Metal Screw: Withdrawal	Shear
Blind rivet	3/16	3/8	#12	#8
Blind rivet	3/16	5/8	#14	#8
Pin drive rivet	3/16	3/8	#12	#10
Nylon spread rivet	1/4	1/2	#8	#8
Self drill screw	#10-32	1/2" wafer	#14	#10

TABLE 16

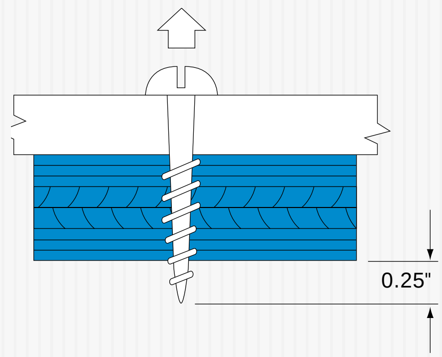
WOOD AND SHEET METAL SCREWS: METAL-TO-PLYWOOD CONNECTIONS[(a)(b)]

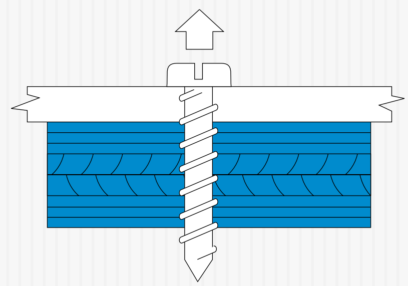
Depth of Threaded Penetration (in.)	Average Ultimate Withdrawal Load (lb)					
	Screw Size					
	#6	#8	#10	#12	#14	#16
3/8	150	180	205	—	—	—
1/2	200	240	275	315	350	—
5/8	250	295	345	390	440	—
3/4	300	355	415	470	525	—
1	—	—	—	625	700	775
1-1/8	—	—	—	705	790	875
2-1/4	—	—	—	—	1580	—

(a) Plywood APA RATED SHEATHING Exposure 1 marked "PS 1" (all plies Group 1).

(b) Average ultimate withdrawal loads from oriented strand board are 60% of the values shown for all-Group 1 plywood.

NOTE: *Table 16* presents ultimate withdrawal loads for wood and sheet metal screws in wood structural panel-and-metal joints, based on analysis of test results. Wood screws have a tapered shank and are threaded for only two-thirds of their length. Sheet metal screws typically have higher ultimate loads than wood screws in the smaller gauges because of their uniform shank diameter and full-length thread. The difference is not as apparent in the larger gauges and lengths because the taper is not as significant. For wood screws, values shown in *Table 16* are based on 1/4-inch protrusion of the wood screw from the back of the panel. This was to assure measurable length of thread embedment in the wood since the tip of the tapered wood screw may be smaller than the pilot hole. This was not a factor for sheet metal screws due to their uniform shanks.





Fastener Use. Tables 13 and 14 provide ultimate shear and withdrawal loads for sheet metal screws for recommended plywood thicknesses fastened to framing. Similar information on nails, staples and bolts may be found under "Fasteners," page 31. The ultimate test loads represent maximum loads carried by the fastener under test at actual failure. Each load must be reduced by a factor appropriate to the intended use. A load factor of 2 is appropriate for some applications in transportation; whereas load factors of around 4 or 5 are often used for permanent applications. Load factors should take into account duration of stress, moisture content, variability among panels and between species. (Values shown are based on physical properties of Douglas-fir.)

In addition to the strength of fasteners shown, consideration may be required for: (1) vibration and the ability to flex without loosening; (2) insulation – nonmetallic fasteners perform best; (3) corrosion – stainless, nonmetallic, or well-plated fasteners are recommended; and (4) ease of use – simple one-step and easy-to-remove. For most linings, the fastener strength is not a limiting factor. Linings seldom apply a critical load to fasteners. *Table 15* presents fastener equivalency.

Fastener spacing of 6 inches o.c. at edges and 12 inches o.c. at intermediate supports should be a minimum, even if the loading is not critical. These spacings aid in holding panels flat and solid. Rail car linings may be fastened to wood sleepers or direct to metal frame. Most frequently, linings are nailed to wood sleepers with pneumatically-driven nails. Scarf-jointed 10' x 30' panels are available to line half a rail car side with one piece. This minimizes joints and simplifies installation.

Cargo Restraint Devices

Cargo must be restrained within a truck or rail car to prevent damage to the cargo itself and the transport unit. Attaching restraints directly to the framework is most desirable, especially with thin liner panels, but fastening to the wall and lining may be necessary in some cases. *Table 16* lists ultimate withdrawal loads for wood and sheet metal screws in plywood-and-metal joints.

See *Table 11* for ultimate loads for cargo restraint devices. Since these values are based upon the strength characteristics of FRP plywood, somewhat lower values will be achieved with conventional 3/4-inch plywood. For detailed discussion of ultimate loads for cargo restraint device fasteners, see page 19 of this manual.

RECREATIONAL VEHICLES AND BUSES

RV manufacturers use APA trademarked structural panels in motorhomes and mini-homes, in travel trailers, fifth-wheel trailers and tent trailers, in vans, pickup campers and all kinds of special-order, custom-made and converted units. Typical applications include floors, cabinets, bed boards, wall linings, counter tops, seats, shelving, roof decking, doors and miscellaneous bracing and mounting. Panel strength, stiffness and impact resistance contribute to safety while the light weight cuts fuel consumption.

Recreational vehicle design, of course, varies widely throughout the industry. This section, therefore, does not suggest specific designs, but presents useful information for designing and working with structural panels. It includes data about panel properties of special relevance to RV and bus manufacturers, and about framing and fastening structural panels.

Panel Selection

Conventional Structural Panels. Several grades of structural panels are recommended for specific RV applications. APA RATED SHEATHING EXPOSURE 1 is particularly well suited for subflooring and wall and roof sheathing. APA RATED SHEATHING EXTERIOR fulfills the same function under high moisture conditions. APA STRUCTURAL I RATED SHEATHING EXPOSURE 1 and EXTERIOR are unsanded structural grades for engineered applications where strength is of maximum importance, such as bracing, gusset plates and mountings.

APA RATED STURD-I-FLOOR is recommended for floors – EXPOSURE 1 for normal service, EXTERIOR for applications subject to severe moisture. These single-floor panels possess high concentrated- and impact-load resistance. UNDERLAYMENT is recommended for application over structural subflooring – EXPOSURE 1 for normal service, C-C PLUGGED EXTERIOR for applications where severe moisture may be present. These touch-sanded panels provide a smooth surface for application of finish flooring. “Sanded face” is a special notation for panels intended for use under thin resilient flooring.

C-D PLUGGED EXPOSURE 1 panels are used for bed bottoms and other structural applications where appearance is not important. This grade is particularly popular for RV flooring, but lacks the puncture resistance of STURD-I-FLOOR and Underlayment grades. C-C PLUGGED EXTERIOR panels are ideal for tile backing and other severe moisture applications.

A-D EXPOSURE 1 and A-C EXTERIOR are sanded grades for applications where the appearance of only one side is important – built-ins, cabinets, shelving, countertops, paneling, and front-end and sidewall linings. B-D EXPOSURE 1 and B-C EXTERIOR are utility sanded panels with one smooth side used for backing, built-ins and bed bottoms. MEDIUM DENSITY OVERLAY (MDO) panels provide an ideal base for paint and exhibit excellent abrasion resistance in such applications as cabinets and built-ins.

These are the basic panels and applications for RV fabrication, although special panels and panel systems are available for other purposes.

Stressed-Skin And Sandwich Panels. High strength-to-weight ratios and efficient use of materials make PS 1 plywood stressed-skin floor and wall panels among the most useful of glued plywood components. Stressed-skin panels typically consist of one or two plywood skins glued parallel to lumber stringers with rigid structural adhesives. The panel functions as a single structural unit with greater load-carrying capacity than its individual members would have if installed separately. The plywood skins take most of the bending stress while the lumber stringers contribute shear strength. With both top and bottom skins and insulative filling, the stressed-skin panel also provides excellent thermal values.

Like stressed-skin panels, plywood sandwich panels offer stiffness, high load-handling capability, light weight and fast, panelized construction. Sandwich panels are prefabricated by sandwiching an insulating core material such as polystyrene or polyurethane foam, or a paper honeycomb, between skins of plywood. Cores and skins are bonded with rigid structural adhesives or direct adhesion of foam to the faces.

For complete information on plywood stressed-skin and sandwich panels, write APA for the following publications:

- *Plywood Design Specification,* Form Y510
- *Plywood Design Specification, Supplement 3 – Design and Fabrication of Plywood Stressed-Skin Panels,* Form U813
- *Plywood Design Specification, Supplement 4 – Design and Fabrication of Plywood Sandwich Panels,* Form U814

Structural Overlays. Fiberglass-reinforced-plastic (FRP) plywood and plywood with aluminum or other metal overlays can add great strength and impact resistance in applications where, as in walls and roofs, structural integrity is especially critical.

TABLE 17

RECREATIONAL VEHICLE SINGLE-FLOOR RECOMMENDATIONS

APA Panel Grade	Maximum Support Spacing (in.)					
	12		16		24	
	Long Dimension Across Supports	Long Dimension Along Supports	Long Dimension Across Supports	Long Dimension Along Supports	Long Dimension Across Supports	Long Dimension Along Supports
	Span Rating[(a)]					
APA STURD-I-FLOOR EXP 1 APA STURD-I-FLOOR EXT	16 oc	16 oc[(b)]	16 oc	20 oc[(b)]	20 oc	24 oc[(b)]

(a) Sturd-I-Floor is manufactured 19/32" or thicker as required by Span Rating. See APA's Product Guide: Grades & Specifications, Form J20. For 12" oc support spacing, 1/2" UNDERLAYMENT grade plywood may be substituted.

(b) Specify 5-ply, 5-layer construction only.

Note: The recommendations in *Tables 17 and 18* for floors have been formulated specifically for recreational vehicle applications. The maximum spans presented for other applications, however, are based on the use of structural panels in residential construction. Because the duration of loads, vehicle life expectancy and code requirements are less demanding in RV than in residential construction, thinner panels than those recommended in the tables are frequently and successfully used. For additional assistance in determining appropriate thickness and spans, contact the APA field representative in your area or the Association's Technical Services Division.

These panels are discussed earlier in this manual under *Panel Types and Properties.* For more extensive information on FRP and metal overlaid plywood, contact *APA – The Engineered Wood Association.*

Special Overlays. Some APA member mills produce high-performance laminated panels with vinyl, polyester resin or other abrasion-resistant woodgrain overlays that are ideal for cabinets, partitions, furniture and other interior finish applications. These panels combine the strength of a plywood substrate with an attractive, durable, easy-to-clean surface. Check with your supplier for available surface patterns and panel thicknesses.

Floors

The leading application of structural panels in recreational vehicles and buses today is floors. Combined subfloor-underlayment (single-floor) construction provides economy, ease of application, stiffness and resilience. Appropriate grades touch-sanded or sanded during manufacture offer a smooth surface for direct application of nonstructural finish flooring.

APA RATED STURD-I-FLOOR panels may be used in combined subfloor-underlayment construction. STURD-I-FLOOR is available with either square edges or precisely engineered tongue-and-groove joints that eliminate the need for blocking or other edge support. Panels can be ordered with either EXTERIOR or EXPOSURE 1 durability classification. For applications subject to continuous moisture or high humidity, specify only EXTERIOR panels. Although some RV manufacturers have successfully used APA A-D or C-D PLUGGED panels, RATED STURD-I-FLOOR panels are recommended because of their greater puncture resistance. This may be less critical under padded carpet.

Table 17 gives recommended support spacings for RATED STURD-I-FLOOR. Panels may be placed either across or along supports. These recommendations were developed specifically for recreational vehicle applications and vary somewhat from those normally allowed in residential construction. Note that STURD-I-FLOOR panels are specified by Span Rating. For even greater floor stiffness, gluing the panels to framing is recommended.

Table 18 gives recommended panel and support spacing combinations for panel subflooring beneath a separate underlayment. Recommended subflooring grades are APA RATED SHEATHING EXPOSURE 1, APA RATED SHEATHING EXTERIOR, APA STRUCTURAL I RATED SHEATHING EXPOSURE 1 and APA STRUCTURAL I RATED SHEATHING EXTERIOR.

Some manufacturers also use sandwich or stressed-skin panel assemblies. (See Stressed-Skin and Sandwich Panels, page 26, for additional information.)

Vehicle floors sometimes can be exposed to a demanding environment. In these instances, excessive moisture may become a problem, especially at panel edges and at fastener penetrations. Untreated wood structural panels, including Marine Grade plywood, might decay if conditions are right for decay organisms to flourish. One solution is to use preservative-treated plywood, especially for floor repairs where decay of untreated panels has occurred.

TABLE 18

RECREATIONAL VEHICLE SUBFLOORING RECOMMENDATIONS

APA Panel Grade	Maximum Support Spacing (in.) 12: Long Dimension Across Supports	12: Long Dimension Along Supports	16: Long Dimension Across Supports	16: Long Dimension Along Supports	24: Long Dimension Across Supports	24: Long Dimension Along Supports
	Span Rating					
APA RATED SHEATHING EXP 1 APA RATED SHEATHING EXT APA STRUCTURAL I RATED SHEATHING EXP 1 APA STRUCTURAL I RATED SHEATHING EXT	32/16	32/16	32/16	40/20	40/20	48/24

Note: The recommendations in *Tables 17 and 18* for floors have been formulated specifically for recreational vehicle applications. The maximum spans presented for other applications, however, are based on the use of structural panels in residential construction. Because the duration of loads, vehicle life expectancy and code requirements are less demanding in RV than in residential construction, thinner panels than those recommended in the tables are frequently and successfully used. For additional assistance in determining appropriate thickness and spans, contact the APA field representative in your area or the Association's Technical Services Division.

Preservative-treated plywood is impregnated with preservatives by a pressure process. The resulting deep penetration of preservative treatment provides protection against decay. The plywood should be marked APA Series V-600 for Exposure 1 panels, and APA series V-611 for Exterior panels, which signify panels suitable for preservative treatment. The plywood should be treated in accordance with American Wood Preservers Association Standard C9 *(Plywood-Preservative Treatment by Pressure Process)*, and, for waterborne preservatives, redried to 18% moisture content or less. For further information, refer to APA Product Guide: *Preservative-Treated Plywood* (Q220).

Walls

Requirements of the Department of Transportation and other regulatory agencies make the structural capabilities of RV wall systems a major design consideration. Panel wall sheathing, corner bracing and front-end and sidewall linings deliver shear strength, rigidity and impact resistance for improved safety and durability. Yet because structural panels are also relatively light weight, fuel economy need not be sacrificed to satisfy structural criteria.

Table 19 gives thickness and support spacing recommendations for panel wall sheathing. Panels may be installed either vertically or horizontally, although vertical application generally provides greater racking resistance.

A-C EXTERIOR and A-D EXPOSURE 1 are the most commonly used grades for front-end and sidewall linings.

Some RV manufacturers have used sandwich wall panels with painted, papered or vinyl-covered plywood as the interior "skin." APA Decorative and 303 Siding panels – both available in a variety of surface textures – provide unique and attractive interior walls and partitions. Several special panels with vinyl or grain-print overlays are also available.

For even greater strength and durability, full wall panels overlaid with a structural material such as aluminum or fiberglass-reinforced plastic are available. These panels can reduce the framing required since the strength of the composite panel is greater than that of the core alone. (See page 26.)

TABLE 19

RECREATIONAL VEHICLE WALL SHEATHING RECOMMENDATIONS

Panel Span Rating	Maximum Support Spacing (in.)
12/0, 16/0, 20/0	16
24/0, 24/16, 32/16	24

Roofs

The frequent use of RV roofs as storage spaces and sun and observation decks demands a stiff decking or reinforcing material that will distribute loads without bending, denting or cracking. APA structural panels are the solution.

Roof construction with APA panels also offers excellent impact resistance and diaphragm characteristics for improved occupant safety. And for ceilings that contribute strength, good looks and improved sound control, APA Decorative and 303 Siding panels are excellent choices.

The thickness and span recommendations for panel roof sheathing in *Table 20* apply to APA RATED

TABLE 20

RECOMMENDED UNIFORM LIVE LOADS FOR APA PANEL ROOF SHEATHING WITH LONG DIMENSION PERPENDICULAR TO SUPPORTS[e]
(APA RATED SHEATHING and APA STRUCTURAL I RATED SHEATHING)

Panel Span Rating	Minimum Panel Thickness (in.)	Maximum Span (in.)		Allowable Live Loads (psf)[c]							
				Spacing of Supports Center-to-Center (in.)							
		With Edge Support[a]	Without Edge Support	12	16	20	24	32	40	48	60
12/0	5/16	12	12	30	—	—	—	—	—	—	—
16/0	5/16	16	16	70	30	—	—	—	—	—	—
20/0	5/16	20	20	120	50	30	—	—	—	—	—
24/0	3/8	24	20[b]	190	100	60	30	—	—	—	—
24/16	7/16	24	24	190	100	65	40	—	—	—	—
32/16	15/32	32	28	325	180	120	70	30	—	—	—
40/20	19/32	40	32	—	305	205	130	60	30	—	—
48/24	23/32	48	36	—	410	280	175	95	45	35	—
48 oc[d]	1-3/32	60	48	—	—	—	290	160	100	65	40

(a) Tongue-and-groove edges, panel edge clips (one between each support, except two between supports 48 inches on center), lumber blocking, or other.
(b) 24 inches for 15/32-inch and 1/2-inch panels.
(c) 10 psf dead load assumed.
(d) Span Rating applies to APA RATED STURD-I-FLOOR "2-4-1".
(e) Applies to panels 24 inches or wider.

SHEATHING EXPOSURE 1, APA RATED SHEATHING EXTERIOR, APA STRUCTURAL I RATED SHEATHING EXPOSURE 1 and APA STRUCTURAL I RATED SHEATHING EXTERIOR.

Framing

APA panels are generally strongest and have the greatest resistance to deflection when installed with the strong axis (panel long dimension) perpendicular to (across) framing members. Depending on orientation and use, it may be necessary to block panel edges. Refer to the span tables in the previous sections for panel thickness and support spacing recommendations. Since the span tables for sheathing grades, except subflooring, are based on the use of structural panels in residential construction, some variation – thinner panels or greater support spacings – may be allowable in recreational vehicle applications. In multi-panel construction, sheathing and STURD-I-FLOOR panels should be spaced 1/8 inch at edges and ends, and UNDERLAYMENT panels spaced 1/32 inch at edges and ends, to allow for any possible expansion due to moisture.

Fasteners

The following fastener data for plywood was developed specifically for recreational vehicle design in conformance with crash-resistant requirements, as well as for applications not necessarily related to crash conditions. The values presented are all ultimate loads and may be applied only to the joint construction described.

Floor-To-Chassis Connections. Federal Motor Vehicle Safety Standard 301 requires that motor homes under 10,000 pounds in weight be capable of withstanding a 30 mph barrier crash with a fuel leakage of not more than one ounce per minute. The Recreational Vehicle Industry Association (RVIA), in conjunction with chassis manufacturers, has developed data on the direction of the forces present during numerous test crashes.

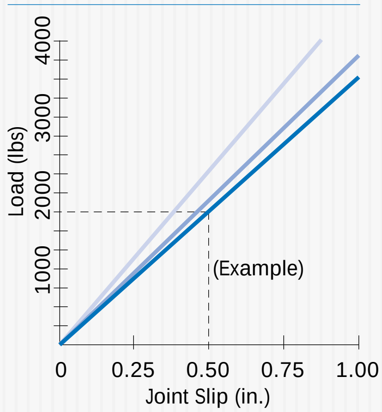
Normal-duration working loads are appropriate in most designs. However, for certain connections it may also be necessary to check the ultimate strength during short-duration crash situations. The floor-to-chassis connections restrict body movement which could possibly puncture fuel tanks or sever fuel lines.

Table 21, which may be applied to crash-related design, presents ultimate loads and joint slips for three floor-to-chassis connections under four angles of applied load. The angles of loading relate to the barrier crashes of the RVIA test vehicles. The largest ultimate load values occur in an all-shear (0°) loading situation. Ultimate loads during uplift of the floor connections (90°) may depend upon design of lumber framing as well as fasteners.

To develop normal-duration design values from the ultimate loads presented in *Table 21*, designers must consider anticipated end-use conditions.

FIGURE 11

LOAD-SLIP RELATIONSHIPS FOR FLOOR-TO-CHASSIS CONNECTIONS, LOADED IN SHEAR



3/8" diameter elevator bolt

3/8" diameter carriage bolt with 1-1/4" diameter washer

3/8" diameter carriage bolt

The service condition of the bolt connection will influence the level of loading. Service condition considerations include 1) load duration or cycle of loading, 2) ability of design to tolerate isolated bolt distress, 3) hazard from distress and 4) moisture content. The service-condition load factor used by the designer may vary from 2.0 for routine design to 5.0 for a conservative design. The latter value may be appropriate and is commonly used for structural applications in buildings.

Suitable design values also involve estimating the ultimate stiffness required of the flooring and any special in-service requirements. Joint slip will affect the stiffness of the floor unit. Designers are responsible for selecting value of slip, or relative joint movement, suitable for specific conditions. The load-slip relationships presented in *Table 21* may be assumed proportional for lower loads. (See *Figure 11*.) Based upon design slip requirements, designers can therefore estimate a design load and the number of connectors required for the floor units.

For example, if the designer were planning to use a 3/8-inch-diameter carriage bolt with a maximum joint slip of 0.5 inch per fastener, what would be the maximum load per fastener? Referring to *Figure 11*, the corresponding load at 0.5-inch slip is 1,750 pounds. This load also corresponds to a load factor of 3700/1750, or 2.11. (See *Table 21*.).

For best joint performance, bolts should be torqued to the levels recommended

TABLE 21

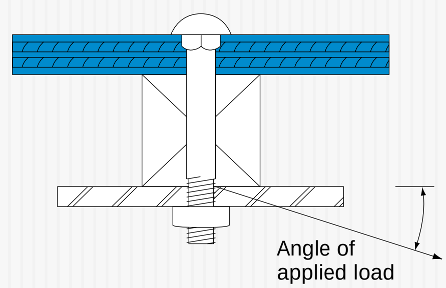
ULTIMATE LOADS – FLOOR-TO-CHASSIS ANCHORAGE

Bolts pass through 1/2-inch Group 1 APA plywood and spruce 2x2 framing to 1/4-inch-thick steel. Bolt torque is 150 in-lbs. Bolt threads bear on steel.

		Angle of Applied Load			
		0°	**15°**	**30°**	**90°**
3/8-inch-diameter carriage bolt	Ultimate Load[(b)] (lbs)	3700	3450	3500	3250
avg. tension yield strength = 4226 lbs[(a)]	Slip @ Ultimate Load (in.)	1.1	1.0	1.1	1.0
3/8-inch-diameter carriage bolt with 1-1/4-inch washer	Ultimate Load[(b)] (lbs)	3950	3700	3750	Load depends upon span length of lumber framing.
avg. tension yield strength = 4226 lbs	Slip @ Ultimate Load (in.)	0.9	0.8	0.9	
3/8-inch-diameter elevator bolt with 1-5/16-inch head diameter	Ultimate Load[(b)] (lbs)	4150	3900	4000	Load depends upon span length of lumber framing.
avg. tension yield strength = 5067 lbs	Slip @ Ultimate Load (in.)	0.8	0.8	0.7	

(a) Bolts were tested in tension in accordance with ASTM A-370 at a loading speed of 0.1 inches per minute.

(b) Static ultimate bolt loads, recorded at a loading speed of 0.1 inches per minute, have been increased by 10% to reflect crash related design.



by the manufacturer. The joints shown in *Table 21* are based on a torque level of 150 inch-pounds.

Adhesives

A wide variety of adhesives are available for use in conjunction with nails or staples in the fabrication of wood structural panel-and-lumber components and assemblies. These include rigid structural, semi-structural, modified polyvinylacetate (PVA) and hot-melt adhesives. The best choice will depend on both the end-use application and production needs. Room-temperature-setting adhesives are usually best for fabricating components and assemblies for recreational vehicle applications. To ensure best performance, specify an adhesive that conforms to a performance standard fitting the end use.

FASTENERS

The integrity of a structure is frequently dependent upon the connections between its component elements. For maximum strength and stability, each joint requires design adapted to fastener type and to the strength properties of individual structural members. Included in the following tables are ultimate lateral and withdrawal loads for various plywood joints.

These values are based upon tests conducted by *APA – The Engineered Wood Association.*

Estimating Allowable Design Loads

It is the responsibility of the designer to select a working load suitable for each particular application. For screws in withdrawal, a working load of about one-sixth of the ultimate load has traditionally been used for long-duration loads. For normal load duration, the long-term working load may be increased by 10 percent. Normal load duration contemplates fully stressing the connection for approximately 10 years, either continuously or cumulatively.

For laterally loaded screws, a working load of normal duration may be approximated by dividing the tabulated ultimate load by 5 or 6. For practically all laterally loaded screw connections shown, the normal-duration working load will correspond to a joint slip of less than 0.01 inch.

For nails and staples in withdrawal, a working load of about one-sixth of the ultimate load has traditionally been used for long-duration loads. For normal load duration, the long-term working load may be increased 10 percent.

For laterally loaded nails and staples, a working load of normal duration may be approximated by dividing the tabulated ultimate load by 5.

TABLE 22

WOOD SCREWS: METAL-TO-PLYWOOD CONNECTIONS

Depth of Penetration	Screw Size	Average Ultimate Lateral Load
1-1/4" thread penetration*	8 ga.	950 lbs
	12 ga.	1310 lbs

*Penetration is into underlying spruce framing.

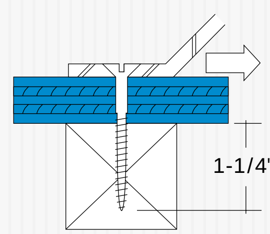


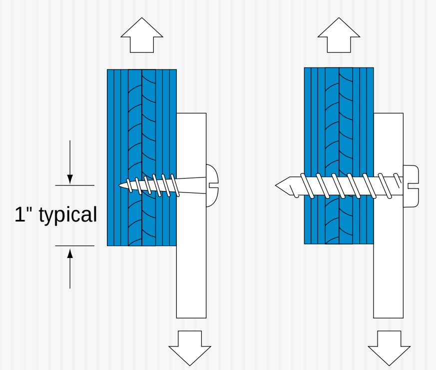
TABLE 23

SCREWS: METAL-TO-PLYWOOD CONNECTIONS(a)

Depth of Threaded Penetration (in.)	Ultimate Lateral Load (lb)(b)					
	Wood Screws			Sheet Metal Screws		
	#8	#10	#12	#8	#10	#12
1/2	415	(500)	590	465	(565)	670
5/8	—	—	—	500	(600)	705
3/4	—	—	—	590	(655)	715

(a) Plywood was APA RATED SHEATHING (all plies Group 1), face grain parallel to load. Side plate was 3/16"-thick steel.

(b) Values in parentheses are estimates based on other tests.



Wood Screw **Sheet Metal Screw**

TABLE 24

NAILS: ULTIMATE LATERAL LOADS IN DOUGLAS FIR LUMBER (lb per nail)

Plywood Thickness (in.)	Common Nail Size			
	6d	**8d**	**10d**	**16d**
5/16	275	305	—	—
3/8	275	340	—	—
1/2	—	350	425	—
5/8	—	350	425	445
3/4	—	—	410	445

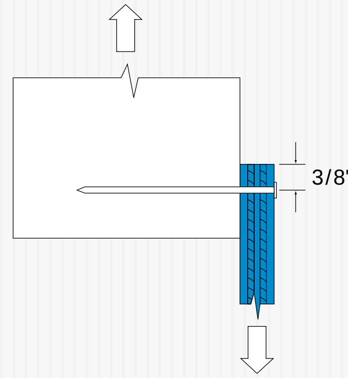


TABLE 25

NAILS: DIRECT WITHDRAWAL FROM LUMBER FRAMING (lb per inch penetration into side grain of member holding point)

Framing Species and Specific Gravity	Common Nail Size			
	6d	**8d**	**10d**	**16d**
Douglas-fir SG – 0.51	160	185	205	230
W. Hemlock SG – 0.48	135	160	180	195
E. Hemlock SG – 0.45	115	135	155	165
Spruce – Pine – Fir SG – 0.42	100	135	155	165
E. White Pine G – 0.34	55	60	70	70

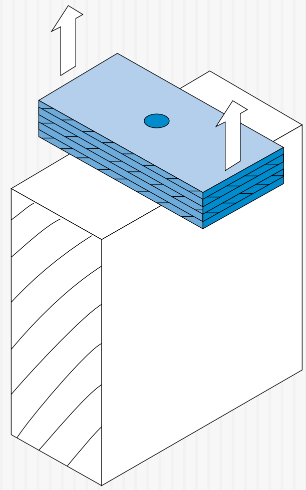


TABLE 26

STAPLES: ULTIMATE LOADS[(a)(b)] (lb per staple)

Penetration into Lumber (in.)	Lateral Load	Withdrawal Load
3/4	160	100
1	180	150
1-1/4	200	200
1-1/2	220	—

(a) Values are for 3/8-in. and thicker plywood, 16 gauge galvanized staples with 7/16-in. crown, driven into Douglas-fir lumber.

(b) Some plastic-coated staples may provide higher values.

TABLE 27

FASTENERS INTO PLYWOOD PANEL EDGE
(Fasteners through 1/4" Group 1 plywood into edge of 3/4" plywood with Group 2 inner plies.)

Fastener Description		Average Ultimate Load (lb per fastener)	
		Withdrawal Loading	Lateral Loading
Staple	1-1/8" long, 7/16" crown, 16 gauge (0.0625")	90	110
	1-1/4" long, 7/16" crown, 16 gauge (0.0625")	105 105	110 110
	1-1/2" long, 7/16" crown, 16 gauge (0.0625")	105	110
Nail	1-1/4" ring shank, 13 gauge (0.086"), 0.205" head – clipped	110	90
T-Nail	1-1/2" smooth, 12-1/2 gauge (0.097") T head – 5/16" wide	130	80

NOTE: Fastening into plywood panel edges will not provide nearly the withdrawal or lateral loading capabilities of fastening into panel faces and is not normally recommended. For some purposes, however, edge fastening may be both necessary and workable.

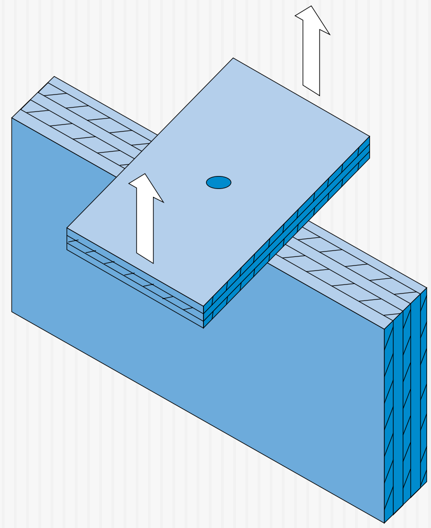


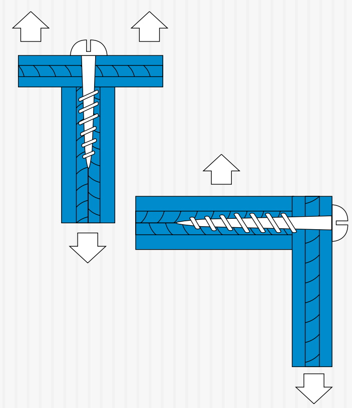
TABLE 28

WOOD SCREWS: PLYWOOD-TO-PLYWOOD EDGE CONNECTIONS[a]

Depth of Threaded Penetration (in.)	Ultimate Lateral Load (lb)[b]			Ultimate Withdrawal Load (lb)[b]		
	#8	#10	#12	#8	#10	#12
1	180	(185)	195	360	(405)	450
1-1/2	180	(185)	195	410	(455)	500

(a) Plywood receiving screw thread was 3/4"-thick APA RATED SHEATHING Exposure 1 marked "PS 1" (Group 2 inner plies).

(b) Values in parentheses are estimates based on other tests.



For bolts, a normal-duration working load may be approximated by dividing the tabulated ultimate load by a factor of 5. For practically all bolted connections shown, this working load will correspond to a joint slip of less than 0.030 inch. The slip value of 0.030 inch brings the bolt into maximum bearing when placed in a hole drilled 1/32-inch oversize. By reducing this load an additional 20 percent, a corresponding joint slip of less than 0.015 inch can be expected in most cases. Loads at this latter slip value have traditionally been used as the maximum allowable lateral load for nailed joint design.

Adjustments for shorter or longer duration of load and for high moisture conditions apply to design values for mechanical fasteners when the strength of the wood (i.e., not the strength of the metal fastener) determines the load capacity. Adjustment of design values for varying duration and combinations of load, as well as for wet conditions, should be in accordance with the current AF&PA National Design Specification for Wood Construction.

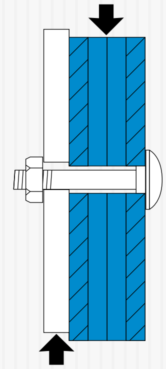
TABLE 29

CARRIAGE BOLTS: PLYWOOD AND METAL CONNECTIONS[a]

Bolt Diameter (in.)	Plywood Thickness (in.)	Plywood End Distance (in.)	Plywood Edge Distance (in.)	Ultimate Lateral Load (lb)[b]			
				Finger Tight		200-in.-lb Torque	
				Without Washer	With Washer	Without Washer	With Washer
3/8	1/2	1-1/2	3	1200	1480	1640	1830
	5/8	1-1/2	3	(1430)	(1710)	(1860)	(2230)
	3/4	1-1/2	3	1710	2520	2160	2700
1/2	1/2	2	3	1280	—	1560	—
	5/8	2	3	(1790)	—	(2320)	—
	3/4	2	3	1940	—	2710	—

(a) Plywood was APA RATED SHEATHING Exposure 1 marked “PS 1” (all plies Group 1), face grain parallel to load. Side plate was 3/16"-thick steel. Bolts were No. 2 N.C. mild steel.

(b) Values in parentheses are estimates based on other tests.



Single shear with carriage bolt

TABLE 30

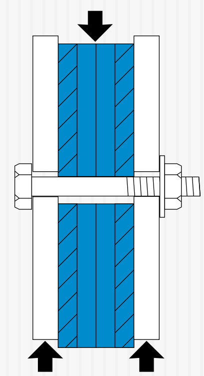
MACHINE BOLTS: PLYWOOD AND METAL CONNECTIONS[a]

Bolt Diameter (in.)	Plywood Thickness (in.)	Plywood End Distance (in.)	Plywood Edge Distance (in.)	Ultimate Lateral Load (lb)[b]			
				Single Shear		Double Shear	
				Finger Tight	200 in.-lb Torque[c]	Finger Tight	200 in.-lb Torque[c]
1/4	1/2	1	3	1180	(1410)	970	(1160)
	5/8	1	3	1200	(1430)	1130	(1350)
	3/4	1	3	1500	(1810)	1380	(1650)
5/16	1/2	1-1/4	3	1490	(1790)	1430	(1710)
	5/8	1-1/4	3	1370	(1640)	1260	(1510)
	3/4	1-1/4	3	2040	(2450)	1770	(2130)
3/8	1/2	1-1/2	3	1730	2080	1510	1820
	5/8	1-1/2	3	1680	(2010)	1650	(1980)
	3/4	1-1/2	3	2120	2560	2330	2790
1/2	1/2	2	3	1870	2240	—	—
	5/8	2	3	(2090)	(2510)	—	—
	3/4	2	3	2240	2960	—	—

(a) Plywood was APA RATED SHEATHING Exposure 1 marked “PS 1” (all plies Group 1), face grain parallel to load. Side plate was 3/16"-thick steel. Bolts were No. 2 N.C. mild steel, with washer.

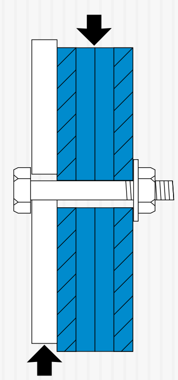
(b) Values in parentheses are estimates based on other tests.

(c) Estimated values for 1/4" and 5/16" diameter bolts apply to torque level recommended by the bolt manufacturer.



Double shear with machine bolt

NOTE: *Tables 29 and 30* present ultimate lateral loads for single-shear and double-shear plywood-and-metal joints. The loaded plywood end distance was four times the diameter of the bolt. All specimens were tested with a 3/16-inch-thick steel side plate, and values should not be applied when steel is thinner.



Single shear with machine bolt

ABOUT *APA — THE ENGINEERED WOOD ASSOCIATION*

APA – The Engineered Wood Association is a nonprofit trade association whose member mills produce approximately 70 percent of the structural wood panel products manufactured in North America.

The Association's trademark appears only on products manufactured by member mills and is the manufacturer's assurance that the product conforms to the standard shown on the trademark. That standard may be an APA performance standard, the *Voluntary Product Standard PS 1-95 for Construction and Industrial Plywood* or *Voluntary Product Standard PS 2-92, Performance Standards for Wood-Based Structural-Use Panels*. Panel quality of all APA trademarked products is subject to verification through APA audit.

APA's services go far beyond quality testing and inspection. Research and promotion programs play important roles in developing and improving plywood and other panel construction systems, and in helping users and specifiers to better understand and apply panel products.

Always insist on panels bearing the mark of quality – the APA trademark. Your APA panel purchase is not only your highest possible assurance of product quality, but an investment in the many trade services that APA provides on your behalf.

For more information about APA functions and services, write *APA – The Engineered Wood Association,* P.O. Box 11700, Tacoma, Washington 98411-0700 or visit APA on the World Wide Web: http://www.apawood.org

OTHER PUBLICATIONS

The following industrial use publications are available from *APA – The Engineered Wood Association*:

APA Product Guide: Grades and Specifications, Form J20. $2

Industrial Panel Selection Guide, Form T200. $5

Materials Handling Guide, Form M200. $3

APA Product Guide: Performance-Rated Panels, Form F405. $2

APA Product Guide: HDO/MDO Plywood, Form B360. $1

U.S. Product Standard PS 1-95 for Construction and Industrial Plywood, Form V995. $3

TRANSPORT EQUIPMENT

INDUSTRIAL USE GUIDE

We have field representatives in most major U.S. cities and in Canada who can help answer questions involving APA trademarked products. For additional assistance in specifying APA engineered wood products, get in touch with your nearest APA regional office. Call or write:

WESTERN REGION
7011 So. 19th St. ▪ P.O. Box 11700
Tacoma, Washington 98411-0700
(253) 565-6600 ▪ Fax: (253) 565-7265

EASTERN REGION
2130 Barrett Park Drive, Suite 102
Kennesaw, Georgia 30144-3681
(770) 427-9371 ▪ Fax: (770) 423-1703

U.S. HEADQUARTERS AND INTERNATIONAL MARKETING DIVISION
7011 So. 19th St. ▪ P.O. Box 11700
Tacoma, Washington 98411-0700
(253) 565-6600 ▪ Fax: (253) 565-7265

Web Address: @
www.apawood.org

PRODUCT SUPPORT HELP DESK
(253) 620-7400
E-mail Address: help@apawood.org

(Offices: Antwerp, Belgium; Bournemouth, United Kingdom; Hamburg, Germany; Mexico City, Mexico; Tokyo, Japan.) For Caribbean/Latin America, contact headquarters in Tacoma.

Form No. G210B/Revised December 1997/0300

A P A

The Engineered Wood Association