PDHonline Course C771 (5 PDH)

Light Gauge Metal Framing - A Sustainable Alternative to Wood

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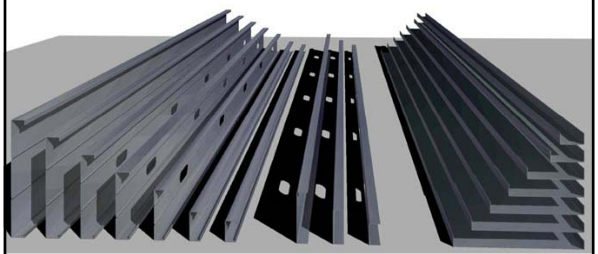
Light Gauge Metal Framing



A Sustainable Alternative to Wood

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LGMF

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Originally known as "Metal Lumber" (in the early 20th Century, when it was first introduced), *Light Gauge Metal Framing* (LGMF) (a.k.a. "Cold-Formed/Rolled Metal Framing") is the most popular alternative to traditional "stick-built" wood framing for residential structures with increasing market share. There are many aspects of LGMF worthy of discussion from both an industry and environmental perspective. But first, we must understand the resources required for the steel/LGMF manufacturing process.

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What's Old is New Again

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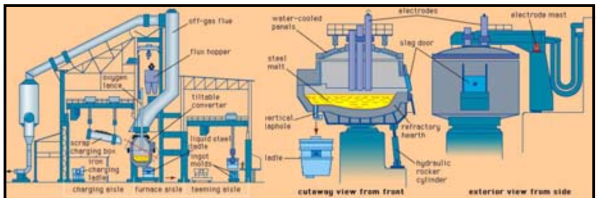

One of the most attractive characteristics of LGMF is the recyclability (100%) of all steel products and the recycled content (25% to 100%) of LGMF. In reality, the recycled content of LGMF is very much dependent upon the method employed in its manufacture: either the traditional ***Basic Oxygen Furnace*** method (left, a.k.a. "Bessemer Process") or the modern ***Electric Arc Furnace*** method (right). The North American steel industry claims to recycle 64% of all steel products. In 2002, this translated to plus 70 million-tons of steel recycled in North America or exported for recycling. This includes such post-consumer products as: cans, appliances, automobiles and construction materials. For more than 150 years, steel has been recycled; its magnetic properties making it easy and efficient to "cull-out" of the solid-waste-stream. There are about 1,800 scrap processors in North America, many in business since the 19th Century. Steel remains the most recycled material on the planet. In fact, more steel is recycled annually than all glass, paper, plastic and aluminum combined.

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There's good reason for all this effort at recycling waste steel and it's not just a case of altruism; it simply makes good economic sense since it's cheaper to use recycled steel than it is to make new steel from virgin materials. However, whether the finished steel product contains 30% or 100% recycled content, the quality and strength of the finished steel product is in no way diminished. The high standards and precision by which steel is made guarantees its quality and status as having the highest strength-to-weight ratio of any building material. Steel's economic good sense for recycling has the advantage of conserving non-renewable natural resources and helps to preserve increasingly diminishing landfill space. Since steel has a long lifecycle, it will always be necessary to mine its essential ingredients:

- **Iron ore**
- **Limestone**
- **Coal**
- **Zinc**

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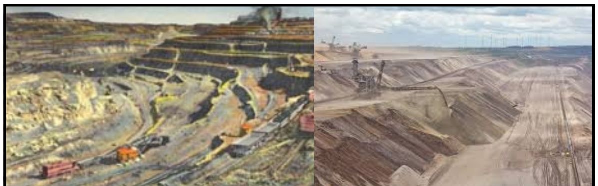

Iron ore and limestone cause the worst eco-disruption since these minerals are obtained primarily from open-pit and/or strip mines on the earth's surface. Such surface mining completely disrupts and destroys valuable ecosystems and leaches large quantities of metals and minerals into local and regional water supplies/sources. In the United States, environmental controls and regulations have limited this ongoing damage, but in other regions where iron ore is mined (i.e. South America) such stringent controls are not in place and the resulting damage to Mother Earth can be devastating. The U.S. *Environmental Protection Agency* (EPA) estimates that surface mining operations cause 48K-tons per square mile of surface erosion annually.

Above L&R: open-pit iron mine (left) and strip mine (right)

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Native Wealth

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Coal for steel-making comes primarily from underground mines in *Appalachia* (western coal is unsuitable for steel making because it lacks the required metallurgical properties necessary). Since the 1890s, the majority of iron ore used to make steel comes from the *Mesabi Range*, in northern Minnesota. Though there is estimated to be an abundant supply that will last for several centuries, the quality of the ore is in decline. This has allowed iron ore imports from South America (Venezuela and Brazil, specifically) to gain a foothold in the North American market. Limestone is also in abundant supply in North America and is typically quarried near steel making facilities.

Left: caption: "Map of Minnesota Two Billion Years Ago With Iron Ranges Indicated"
Right: caption: "Mesabi Range Underground Mine Shaft 'In the Minnesota Arrowhead Country'"

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Zinc (for galvanizing) is mined in a variety of regions in North America. Though zinc supplies are plentiful, the byproducts of the "Smelting Process" (to obtain zinc for galvanizing from zinc ore) is environmentally controversial. Wastewater from zinc smelting sites contain heavy metals such as Cadmium, Chlorinated Compounds and Toxic Organics. Many former zinc smelting sites are now "Superfund" cleanup sites. About one-third of the zinc consumed in the United States is produced domestically; the balance comes from Mexico, Canada and other countries. Of the one-third produced in the U.S., about one-third is reclaimed/recycled. Recycled galvanized steel is melted whereby the zinc evaporates and is recaptured for reuse.

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REUSE
REDUCE
RECYCLE

There are tangible and significant positive results from recycling steel. Consider that each ton of recycled steel saves:
- 2,500 pounds of iron ore
- 1,400 pounds of coal
- 120 pounds of limestone

From a lifecycle perspective, energy savings due to LGMF's airtight capabilities for a building envelope, long structural life and the conservation of iron ore resources save the electrical energy equivalent to powering eighteen million (about 20%) of American homes. On the job site, LGMF represents only about 2% of the solid waste produced; primarily due to its recyclability and ease of separation from other materials, such as wood, that generates about 20% of the solid waste at a construction site.

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All LGMF, no matter what the manufacturing method used, contains a minimum of 25% recycled steel content and as much as 100%. Whatever the recycled content percentage, it's always 100% recyclable. Steel made by the traditional *Basic Oxygen Furnace* method typically contains about 30% recycled content, whereas steel made by the *Electric Arc Furnace* method is made from up to 100% recycled content typically. The 64% recycling rate used by the steel industry includes "home scraps" - steel scraps that never leave the mill. Such scraps are not considered "recycled" and/or "recovered" materials by most industries. As well, steel scrap collected domestically and exported is included in this percentage. This steel does not return as recycled content in products manufactured in the U.S. For these reasons, the overall realistic recycled content of domestically produced steel is about 46%.

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The *Electric Arc Furnace* (EAF) process is the modern method for manufacturing steel and is most widely used where LGMF is concerned. It's more energy efficient and relies on recycled steel to a much higher degree. In the 1970s, "Mini-Mills" began to appear in North America. Initially used to fabricate heavier steel products such as rebar, steel plate and I-beams (via "hot-rolling"), the EAF process directly melts steel scrap to make new steel. *Nucor Steel Inc*. went a step further by producing steel sheets from steel scrap directly using the EAF process - this was revolutionary. Though the process left surface imperfections unacceptable to the automobile and appliance industries, it was ideal for LGMF where these imperfections were irrelevant. At that time, the process was using 91% recycled steel. With 21st Century technology, the recycled content using the EAF process is typically at or near 100%.

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LEED
Leadership in Energy and Environmental Design
GREEN BUILDING

The advent and success of the U.S. Green Building Council's LEED (***L**eadership in **E**nergy & **E**nvironmental **D**esign*) green building certification/rating system has increased the appeal and use of LGMF. Under LEED, points towards certification are earned while incorporating LGMF in a building's design since the steel used in LGMF - whether manufactured by the *Basic Oxygen Furnace* method or the *Electric Arc Furnace* method, exceeds the minimum goals set forth in the LEED criteria (for earning points toward certification under "recycled content").

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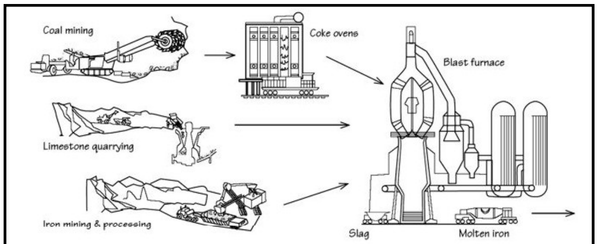
Part 2

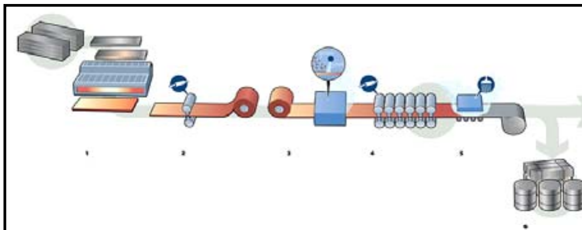
Manufacture

Let's Roll

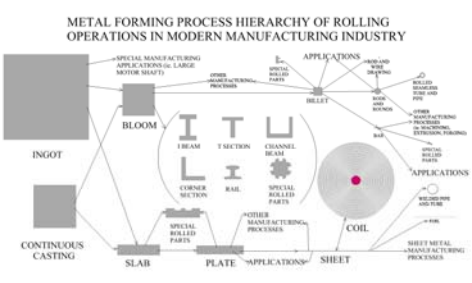


Steel sheets are formed by pouring molten steel into an ingot mold or continuous caster. There, it solidifies into slabs which are large, rectangular shapes. These large slabs are then passed through rollers that reduce the steel slab; based on desired thickness and strength, into thin sheets. These thinner sheets are run through a molten bath of zinc. This is known as the "Hot-Dip Galvanizing" (HDG) process. The long sheets are rolled into coils ranging in weight from 20K to 25K pounds. These large coils are manufactured to the cold former's specifications for base metal thickness, type, strength and coating weight.

Above: caption: "Schematic of galvanized sheet steel manufacture"



1. **The slabs are heated in slab furnaces to the correct rolling temperature of about 1,250-degrees Celsius.**
2. **In the roughing mill, the slab thickness of 220mm is reduced to 30mm. The steel is coiled and increases in length from 11 meters to a coil of 80 meters of heavy plate.**
3. **The plate is cleaned to remove mill-scale in several stages during hot rolling.**
4. **The hot-rolling mill is a wide strip mill that can roll the whole width of the slab in one pass through the six strands. Extreme forces are applied to the rolls that roll the steel to a thickness of between 16mm and 1.8mm. The rolling speed is 120 km/h at the end of the hot rolling mill. If the sheet is rolled down to a thickness of 2mm, the sheet will have grown in length from 80 meters to 1,300 meters.**
5. **The sheet is cooled before it is coiled onto a coil. The material temperature during cooling may be 600-degrees Celsius or below.**
6. **Hot rolled sheet steel is sold in coils or cut to length.**



The steel industry's own initiatives, advancements and investments in new technology along with increased use of steel scrap is a big part of why steel prices have remained relatively stable and why LGMF is so attractive as compared to lumber: price stability.

Left: hot-rolled steel coil. Sheet steel represents about half of all steel consumed worldwide.

Base Metal Thickness

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It's important to note that the terminology used when referring to base metal thickness of LGMF (cold-formed) components has undergone a transformation in recent years. The "G" in LGMF gives us the familiar term "Gauge." Many end-users found it difficult to recall, off-hand, the exact base metal thickness of, for example, standard 25-gauge non-load bearing framing components as represented by its decimal equivalent of an inch (0.0179). The new terminology solved this problem by using the actual base metal thickness itself as the defining element. Thus, a 25-gauge framing component is now also referred to as "18 mil." A "mil" represents 1/1,000th (0.001) of an inch (0.0179~0.018~18 mil). Manufacturers, design/construction professionals and industry organizations, such as the *Steel Framing Alliance* (SFA) and the *American Iron and Steel Institute (*AISI), have adapted to this change. The following is a gauge/mil comparison:

Gauge	Thickness	Mils
25	0.018	18
22	0.027	27
20	0.033	33
18	0.043	43
16	0.054	54
14	0.068	68
12	0.097	97

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HDG

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The American Iron and Steel Institute's "Prescriptive Method" (PM) designates ASTM A653 for hot-dip galvanizing of LGMF components. This standard for corrosion protection breaks down as follows:

- Non-structural - G40
- Structural - G60
- Harsh environment - G90

By weight, LGMF components are 3 to 5% zinc (depending on coating thickness which is the result of the bath of molten zinc the bare steel is subjected to after being cleaned, pickled and fluxed). This anti-corrosion treatment effectively protects the steel from corrosive damage for its entire lifecycle and can itself be recycled at the end of the structure's lifecycle. Corrosion resistance is proportional to the zinc coating thickness (i.e. G40 = 40 ounces per square-foot). The weight (thickness) of the coatings (as set forth by ASTM A653) are defined as follows:

- G40 and G60: "For members located within building envelope and adequately shielded from direct contact with moisture from the ground or the outdoor climate"
- G90 and heavier (recommended for): Additional protection requirements (i.e. oceanfront buildings). As compared to G60, G90 is;
  * 50% thicker
  * Should last 1.5 times longer

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Making Contact

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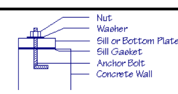

Pressure-treated lumber; used to protect against termites, fungal decay, insects etc., often comes in contact with steel framing components when used as sill (above) and/or top plates, truss plates, metal connectors and fasteners. Of the three types of pressure treatments used to force preservatives into the cellular structure of wood: waterborne, creosote and oil-borne, waterborne is typically used for building materials. *Chromated Copper Arsenic* (CCA), which uses arsenic as the preservative, has been banned. As of December 31st 2003, CCA ceased being produced for residential and consumer use after decades of use by the construction industry. Replacing CCA were a new generation of waterborne preservatives, most of which are copper-based, such as:

- Alkaline Copper Quat (ACQ)
- Copper Azole (CBA-A/B)
- Ammoniacal Copper Zinc Arsenate (ACZA)

Unfortunately, testing has demonstrated that all of these copper-based preservatives are much more corrosive to LGMF than CCA ever was. This has caused concern in the steel framing, wood fastener, connector and metal plate truss industries.

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Copper-based PT manufacturers recommend using coatings greater than G90, but this is not a practical, cost-effective alternative. Rather, there are three more preferable alternatives:

• **Avoidance**: typically, building codes do not require a wood sill plate beneath steel framing. This eliminates the need for a sill plate - the most common PT/LGMF interface. Also, a wood top plate is not required in LGMF (axial loads are carried downward via framing alignment). However, a solid wood sill plate helps greatly to span the dips and valleys along the top of a foundation wall.

• **Isolate**: use of closed cell foam, heavy plastic, paint or felt paper proves useful in providing a barrier between PT wood and LGMF. In any event, the integrity of the barrier must be maintained. Regardless of the barrier, fasteners made of metal penetrate the barrier and seat in the PT wood. Self-tapping screws, typically used in LGMF, are subject to corrosion when in contact with PT wood unless properly protected. Therefore, care should be taken in selecting fasteners and manufacturers recommendations followed when this condition occurs. Stainless steel fasteners, when in direct contact with galvanized metal, will accelerate corrosion due to the electrolytic action between the two dissimilar materials.

• **Borate-Based**: if avoidance and/or isolation are not practical, then use of sodium borate (SBX) PT wood is recommended. Tests have shown that SBX is less corrosive to galvanized steel than CCA. Since it's water soluble, it should not be used where it will be exposed to the elements and should be covered during transport and storage on site. As such, SBX PT wood is especially good for use as sill plates, if they're included. Pressure treatments are often referred to by trade names and have many variations.

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Cold Forming

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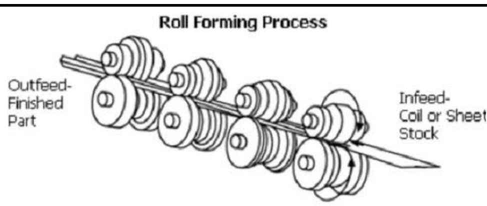

At the cold former, a "slitter" is used to reduce the large coils to a proper, precisely measured width for the intended production run (a.k.a. "slit coil"). The steel's surface is then "pickled" in a bath of sulfuric or hydrochloric acid. Allowed to cool, the resulting strips (a.k.a. "ribbons") are then fed into a roll forming machine where it passes through a series of dies (a.k.a. "rollers") that bend the steel to the desired profile. This entire process is computerized and will hold a tolerance of within 1/8-inch for any pre-determined length. Typically, 40-feet is the maximum length for LGMF members since a flatbed trailer is 40-feet long, but longer, custom lengths are possible as a special order production run. The computer controls the number and length of members and the dies in the roll forming machine are set to roll the size and shape desired.

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Top Left: a single mandrel un-coiler (for slit coil) can handle up to six thousand pounds, while an optional double mandrel unit allows operation from one side while slit coil is loaded simultaneously on the other.
Top right: dies bend the slit coil steel to the desired LGMF profile
Left: the cold formed steel shapes are cut precisely to the desired length

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Long, cut-to-length framing members have several advantages; particularly for floor joists. Lap splices can be avoided since floor joists can be ordered to the full width of the house. This eliminates the need to order only stock-lengths and reduces field cutting significantly. As the shapes emerge from the roll former, a stamp imprints an embedded code on the surface of the steel member that allows inspectors, tradesmen, etc., to identify the framing component according to:

• Manufacturer
• Base Metal Thickness (uncoated)
• Coating Weight
• Minimum Yield Strength

For example, a code stamp on a stud might read: XYZ 0033 G60 33KSI. Decoded, this stamp tells the world that the XYZ manufacturing company fabricated this framing component with a 33 mil (20 gauge) base metal thickness, applied a G60 weight hot-dip galvanized coating and used 33KSI (Kips per Square Inch) or 33,000 PSI (Pounds per Square Inch) minimum yield strength steel to do so (one "Kip" equals 1,000 pounds). Not all cold rollers provide such a stamp, but it is fast becoming standard practice (in lieu of a paper label) - particularly among the larger manufacturers.

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One-Stop Shopping

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For the end-user, LGMF can be purchased directly from the cold former or, more typically, from a distributor/supplier (a fabricator may significantly increase their price for lower production runs for custom lengths). Though field cutting LGMF to length is not yet as efficient as cutting wood, it still may be cost effective to consider avoiding a price premium for custom lengths by ordering stock lengths and field cutting them to their desired length. On the other hand, distributors/suppliers such as lumber yards and/or supply houses are typically "one-stop shopping" venues which are price competitive with manufacturers, easily accessible and nowadays stock an inventory of commonly used LGMF components such as stud, joist, track, angle, etc., in standard stock sizes and lengths. Typically, they do not cut-to-length as do cold formers.

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Part 3

Cons & Pros

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Achilles Heel?

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There are many arguments for and against the use of LGMF. Ultimately, this debate boils down to include the following aspects of LGMF:

- Thermal performance
- Insect/pest resistance
- Seismic (earthquake) resistance
- Fire resistance
- Mold resistance
- Environmental benefits

Let's begin with the first (and most controversial) aspect: ***Thermal Performance***.

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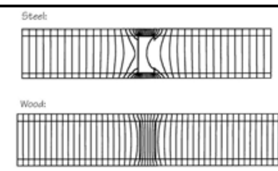

By its very nature, steel is a naturally conductive material, whereas wood has low conductivity and actually has insulating properties. In fact, generally steel is 400x more conductive of heat as compared to wood. A 1.5-inch thick wood stud is +/-10x less conductive of heat than a 20 gauge metal stud. Thus, when metal framing is used at the perimeter of a building envelope - between the interior and exterior spaces - "Thermal Bridging" (a.k.a. "Thermal Telegraphing") will occur. Heat flow increases slightly around a wood stud, but converges on either side of a metal stud at the flanges.

Above: caption: "Heat flow lines: Each line represents an equivalent amount of heat flow through the wall. The concentration of heat flow increases slightly around the wood stud, and much more dramatically at the steel stud. The many lines at each side of the steel stud seem to disappear because they all converge (overlap) at the flange."

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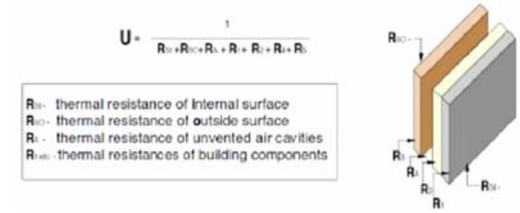
Framing member & spacing	Nominal cavity insulation	Combined cavity & framing R-value (w/o sheathing or air films) Wood-framed	Steel-framed
2x4 16" o.c.	R-11	R-9.0	R-5.5
	R-13	R-10.1	R-6.0
	R-15	R-11.2	R-6.4
2x4 24" o.c.	R-11	R-9.4	R-6.6
	R-13	R-10.7	R-7.2
	R-15	R-11.9	R-7.8
2x6 16" o.c.	R-19	R-15.1	R-7.1
	R-21	R-16.2	R-7.4
2x6 24" o.c.	R-19	R-16.0	R-8.6
	R-21	R-17.2	R-9.0
2x8 16" o.c.	R-25	R-20.1	R-7.8
2x8 24" o.c.	R-25	R-21.2	R-9.6

Above: caption: "Impact of framing on Wall R-Values" 43



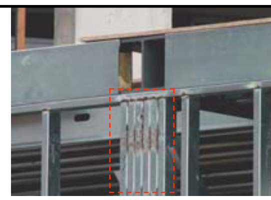
Consider a wall with wood and/or metal framing spaced at 24-inches on-center and R-13 cavity-fill insulation. The wood-framed wall has two times the R-value as the same wall framed with metal studs. Energy codes/standards, such as the *American Society of Heating, Refrigeration and Air-Conditioning Engineers* (ASHRAE) 90.2 and the model energy code are typically developed around the "U-value" (thermal resistance) of an assembly. This is the ability of a wall or other building element to retain warm or cold air within the building envelope.

Above: caption: "The U-value is the inverse sum of the resistance of each building material and surface resistance to the outer and inner faces of the material build-up of the element. The U-value is the reciprocal of the sum of all the resistances instead of the sum of all conductance because the interaction of the building element to outside environments is measured in terms of surface resistance, so for consistency, the behavior of the built elements are also expressed in terms of resistance." 44

Nominal Framing Depth	Nominal Insulation R-Value	X	Correction Factor	=	Effective R-Value
4" @ 16" O.C.	R-15	X	0.43	=	R-6.4
4" @ 24" O.C.	R-15	X	0.52	=	R-7.8
6" @ 16" O.C.	R-21	X	0.35	=	R-7.4
6" @ 24" O.C.	R-21	X	0.43	=	R-9.0

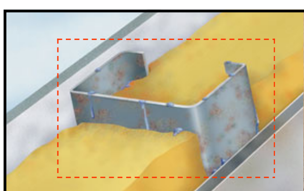
Use of the *Parallel Path* test method, which assumes heat flows straight through a wall and follows the path of least resistance (for the purpose of determining heat flow through a building envelope), is acceptable for wood framing but not for LGMF. Near a steel stud, heat moves sideways through a wall and then travels through it. Recognizing that there was, indeed, a significant reduction in thermal efficiency when LGMF is used at building perimeter walls, ASHRAE issued corrected values for LGMF exterior wall assemblies.

Above: caption: "Effective R-values of steel stud wall assemblies with insulation installed between the stud framing per ASHRAE 90.1" 45



In the mid-1990s, the *National Association of Home Builders* (NAHB) research center found that heat flow calculations used by engineers were flawed in that they failed to correctly estimate the poor performance of the framing when incorporated into an exterior wall assembly. NAHB found that mock-up tests and sophisticated computer modeling were the only reliable means of determining heat flow through such ass-emblies. LGMF used in residential con-struction for floors, walls and roofs typically uses 24-inch O.C. spacing (due to steel's high strength-to-weight ratio) rather than the standard 16-inches O.C. used in traditional wood framing. An NAHB study found that this increased spacing (fewer framing members) helped mitigate some of the thermal penalties encountered with LGMF. Care should be taken to avoid "clustering" of steel studs in exterior walls. This can/will create "cold-spots" in the wall due to insufficient or missing batt insulation in the web cavities of the clustered studs. 46

Above: example of clustering of stud framing at exterior wall (highlighted)



In effect, thermal bridging undermines the tightness of the building envelope and causes increased heating/cooling loads, thus requiring larger HVAC equipment. In the Northeast U.S., typically about 80% of the annual energy costs of a commercial building is for cooling rather than for heating. "Utopian" walls: those without corners, band joists, rough openings, etc., were often used as test models. This created misleading data. Use of less than full-width insulation (to fill the open web on one side of the cavity between metal studs) results in circumvention of the insulation through the gap at the web of the C-stud open to the cavity. With wood framing, full cavity width insulation is not used due to the solid wood stud's thickness occupying a portion of the cavity itself.

Left: full-width cavity insulation (required for LGMF) fills the open-web of the C-stud on one side and butts up to the web on the other side

Right: installing less-than-full-width batt insulation in a woof-framed wall. The batt will be slightly wider than the actual space between the wood studs for a friction-fit 47

Ghosting

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"Ghosting" is the depositing of dirt and dust particles on exterior walls/ceilings, typically along the length of the framing member/s. This occurs when the surface thermal gradient is greater than 32-degrees(F). Under these conditions:

- Particles adhere to the colder areas of the wall, highlighting the location of framing members
- Ghosting has a higher incidence where occupants smoke and/or frequently burn candles

Ghosting is not unique to LGMF, but tends to occur more often because of the higher thermal conductance of steel. If the mean temperature differential between the inside and outside temperature is 50-degrees(F) or greater for two or more days, there is a greater chance of ghosting to occur within the first year of occupancy (it generally occurs during the winter months). Attachment of insulating sheathing on the exterior side of the wall will effectively eliminate the incidence of ghosting.

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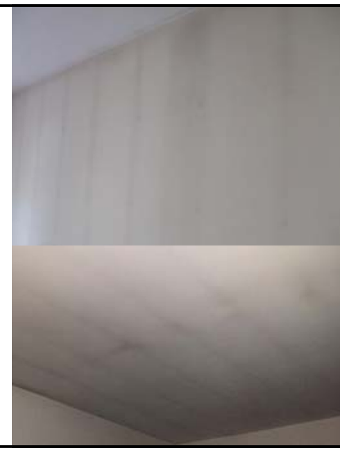

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A study by the *Journal of Thermal Insulation,* in July 1994, found that the R-values achieved in a simple ranch-style home with LGMF exterior walls was 22% lower than the Utopian wall's R-values. Also in 1994, an NAHB test showed that the use of insulating sheathing (i.e. foam board), in conjunction with the framing, increased the thermal resistance of the wall assembly by about R-1. Essentially, there are five methods to help offset, but not eliminate entirely, the effects of Thermal Bridging:

- Modify Steel Studs
- Use of Insulating Sheathing
- Add Strapping
- Framing Configuration
- Air Tightness

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<u>Modify Steel Studs</u>

Some manufacturers offer "Thermal Studs" that include perforations or gaps that remove a substantial portion of the web of the stud, thus reducing the path for heat transfer. Another variation includes "nubs" on the stud flanges to provide a self-furring effect for the stud to minimize the contact area between the metal stud itself and the substrate material (typically wood or gypsum-based sheathing). Altering the stud's web material to be non-conductive and/or jacketing the stud in insulation are other options.

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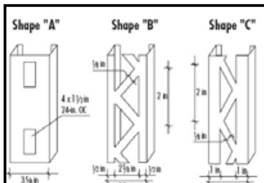

Exterior sheathing	R in Center of Cavity (in hft²F/Btu)	R test (in hft²F/Btu)	Framing effect (*f*)
½-in plywood	12.8	7.9	38.2%
½-in EPS	15.2	11.4	25.1%
1-in EPS	17.6	13.7	21.1%
2-in EPS	23.0	18.9	17.8%
2-in EPS, no cavity insulation	20.69	18.00	13.0%

* *f* = 1–(R test / R in center of cavity) x 100%

<u>Left</u>: caption: "Opening on the stud web area reduce the heat conducting area of the stud web, reducing the thermal bridge effect." A very intensive heat transfer through a steel stud's web causes thermal "shortcutting" in LGMF construction. Reducing the stud web area (the area that forms a bridge between two steel flanges) can be an effective method of mitigating the problem. Shape A is a traditional LGMF stud design with 1-1/2" by 4" holes (a.k.a. "knock-outs") punched in the studs. The next two shapes (B and C) represent the thermal or "expanded-channel" stud design. The stud web area was reduced by 11% in the shape A stud, by 63% in the shape B stud and by 39% in the shape C stud. The section area of the center of the stud web was reduced by 16% for shape A and by 87.5% for shapes B and C. A previous study made by *National Research Council of Canada* found a 50% reduction of the thermal bridge effect in walls with shapes similar to B and C (as compared with standard steel stud walls).

<u>Right</u>: caption: "R-value and Framing Effect '*f*' {*f* =1-(R test / R in center of cavity) x 100%} in 3-5/8 Steel Stud Walls." Walls with a reduced stud web area are much more thermally efficient than walls with traditional studs. The lowest f-values were found for the walls containing shape B studs. However, shape C studs are significantly stronger and their thermal performance is only slightly lower than that of shape B studs. With shape C studs, the stud web area was reduced about half as much as it was with shape B studs. Since walls containing studs B and C have similar thermal performance, building with shape C studs would be preferable, due to their superior structural stability.

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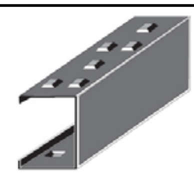

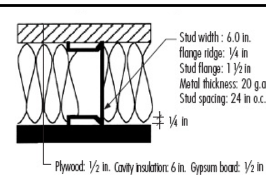

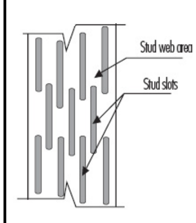

<u>Top Left</u>: caption: "Steel Stud with Extruded Dimples. Extruded dimples on a steel stud also reduce contact between the stud and the sheathing and improve the wall R-value."

<u>Top Right</u>: caption: "Steel Stud Wall with Vertical Ridges on Stud Flange Area. Vertical ridges on a steel stud reduce the contact area between the stud and the sheathing material and improve the whole wall R-value."

<u>Left</u>: caption: "Slotted Web Stud. A series of slots in the stud web reduces the heat transfer area." This interesting design is from Scandinavia. The web area is divided by several courses of slots. They significantly reduce effective heat conduction area on the stud web.

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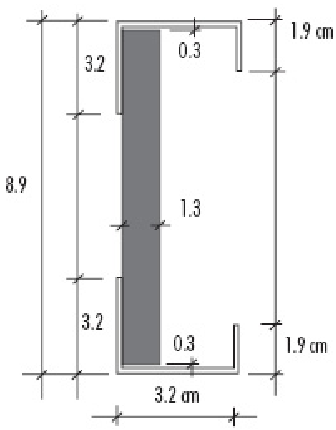

Left: caption: "Steel Stud with OSB Web. Replacing steel in the stud web with OSB increases the stud's thermal resistance." Another way of minimizing steel stud web heat transfer is by replacing the steel web with a less conductive material, such as plywood or *Oriented Strand Board* (OSB). A novel stud design developed by the *Florida Solar Energy Center* (FSEC) makes use of this technique. FSEC's combined wood/metal studs consist of two metal flanges and a connecting web made of OSB or plywood. The FSEC wall cavity can be insulated with R-11 or R-13 fiberglass batts. In tests, using the FSEC studs resulted in a 39% improvement in R-value, as compared to using a traditional LGMF stud.

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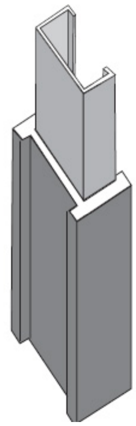

Left: caption: "'Stud Snuggler.' An interlocking foam cover wrapped around the steel stud protects the interior from intense heat transfer." Using insulation spacing between the studs and the sheathing is another way to reduce heat loss. Such insulation also reduces transverse heat transfer through the stud flanges. This kind of heat transfer increases heat loss in steel framed structures. In 1993, *Stud Snuggler* foam shapes were developed to cover the studs. These shapes add highly efficient thermal insulation only in the locations where it is absolutely necessary (i.e. in the stud flange areas). At the same time, the wall cavity is insulated with fiberglass batts, which are significantly less expensive than rigid foam sheathing. This reduces the thermal bridging effect at a relatively low cost. Similar technology was developed in Finland for steel trusses. This idea was later adopted in the U.S. in the form of "snap caps" (foam caps that attach to the stud flange/s with an adhesive).

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Wall construction	Tested R-value hft²F/Btu	Improvement hft²F/Btu	Improvement %	Framing Effect %
Gypsum board, traditional 3⁵/₈-in. studs, R-11batts, gypsum board	7.9			38.2
Gypsum board, traditional 3⁵/₈-in. studs, 1-in. foam profiles on studs, R-19 batts, gypsum board	16.3	8.4	106.3	13.0

Above: caption: "Thermal Performance of walls with 1-inch Thick Stud Snugglers." In tests, 1-inch thick foam shapes covered the studs only in locations where strong thermal shortcuts were generated by the steel stud. A comparison of the R-value of this test wall to that of walls made with conventional steel studs revealed excellent performance, both thermally and structurally. With its simplicity, high R-value (R-16), low *f*-value (13%) and low cost, this system demonstrates that, with proper thermal design, LGMF exterior walls can perform as well as their wood framed counterparts.

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Use of Insulating Sheathing

As mentioned, the use of insulating sheathing on the exterior side of LGMF increases the R-value of the wall by about R-1. Translated, tests have demonstrated that this represents up to a 20% increase in the overall R-value of the wall assembly. Though not a silver bullet, use of insulating sheathing is the easiest, most cost-effective means by which to increase the R-value of a LGMF exterior wall and offset the effects of Thermal Bridging.

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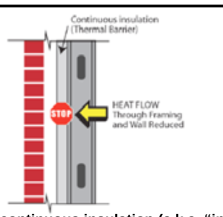

Left: continuous insulation (a.k.a. "insulating sheathing") is not new and has been in successful use for more many years. However, it is now prominently featured in newer energy codes because it's known to be a very effective way to insulate building envelopes for energy savings. Continuous insulation provides the ability to resist heat transfer; this creates what is known as a "thermal blanket" over the building envelope, ultimately conserving energy and increasing occupant comfort. Continuous insulation increases the overall thermal performance of the wall assembly and, in turn, the entire building, by blocking Thermal Bridging between the interior and exterior. Rigid foam plastic sheathing materials (i.e. *Extruded Polystyrene* or "XPS") are preferred for continuous insulation because of their relatively high R-value (per inch) and low cost to meet or exceed energy code requirements.

Right: installing insulating sheathing over LGMF

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Add Strapping

Another method used to short-circuit the Thermal Bridge at the flanges of metal studs is to apply a "thermal break" in the form of felt building paper along the entire surface of the exterior-side stud flange. This serves as a disconnect since the felt paper is not conductive.

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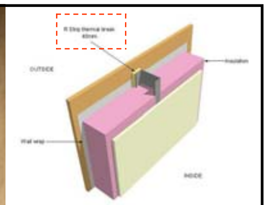

Above: caption: "Thermal breaks minimize the risk of condensation and ghosting. They also ensure there is a good overlap between the wall insulation and thermal break to stop bridging at the edges of the flange and minimizes the effects of poor installation."
Left: caption: "By simply adding one strip to each stud edge, ***Ther-mablok*** interrupts the thermal bridging process through the studs."

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Framing Configuration
Though LGMF can be used as a "piece-for-piece" re-placement of wood framing, it need not be used that way. Hybrid framing configurations are possible whereby 2x6 or 2x8 wood studs are used at the exterior walls and/or roof rafters (greater depth of framing member increases insulation thick-ness/R-value). Trimmers/headers at the floor along the perimeter of the building may also be wood framed. Interior walls (load bearing and/or non-load bearing), floor joists, etc., can be made from LGMF.

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Air Tightness
Use of good detailing, particularly around door and window openings (where most air infiltration occurs), is another way of keeping the outside air out and the inside air in. LGMF is particularly good at creating a tight building envelope due to its uniformity and dimensional stability. Designs that min-imize door/window openings also contribute to thermal eff-iciency. Energy codes typically take this into consideration for determining insulation requirements and offer energy credits for doing so.

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Insulating LGMF

The *American Iron & Steel Institute* published the "Thermal Design Guide for Exterior Walls" (RG-9405) in 1993. "Appendix C" provides guidelines for the amounts of insulation required to properly insulate homes constructed with LGMF. Three methods for determining insulation levels are included:

- **Thermal Degree Days**
- **Thermal Zone Map**
- **Chart Method**

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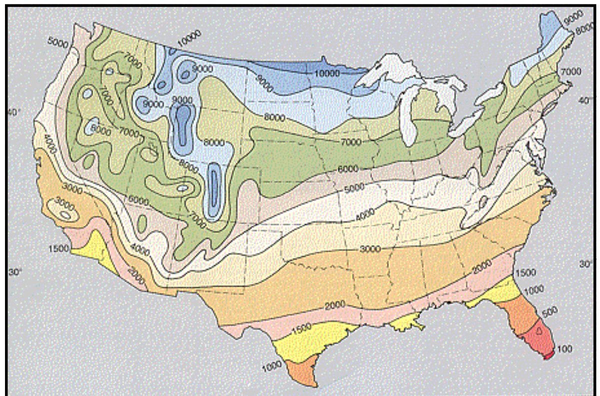

Above: caption: "Heating Degree Days Map of the United States"

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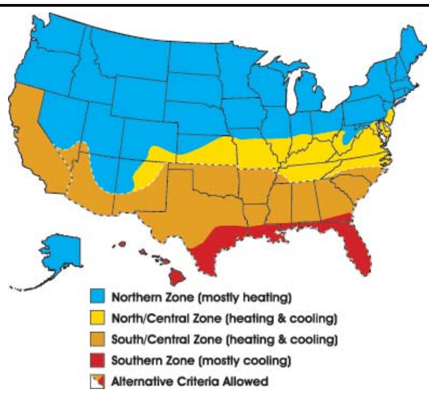

Above: caption: "Thermal Zone Map of the United States"

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Most important when insulating LGMF is the complete filling of the cavity between framing members (including the open web on one side). Full cavity width, friction-fit batts must always be used with LGMF. For kraft-paper faced insulation without flanges (a.k.a. "lips"), the insulation should be taped or glued to the studs to hold it in place. Spray-applied insulation is acceptable as long as it fills the cavity completely. Areas requiring thermal insulation (to avoid cold-spots) in LGMF structures include the following:

- **Exterior walls**
- **Jambs and headers in exterior walls**
- **Built-up members in exterior walls**
- **Corner/multiple studs in exterior walls**
- **Behind outlet boxes in exterior walls**
- **Full-width between ceiling joists below unheated attics, garages or where there are heated rooms above the ceiling/living space**
- **Below stairways and within knee walls inside of unheated attics**
- **In cathedral ceilings**
- **Around the rim joist/track at building perimeter**
- **Between joists that are over a crawl space or above an unheated living space**

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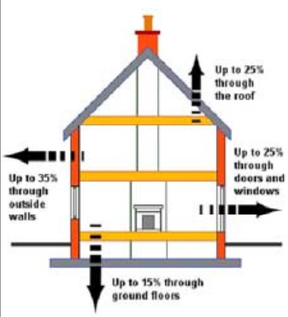

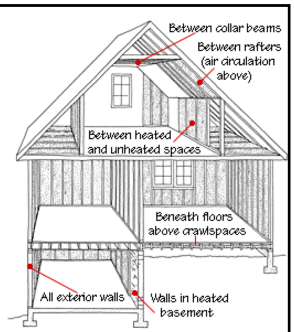

Left: caption: "Heat Loss from a Badly Insulated Home"
Right: caption: "Where to Insulate"

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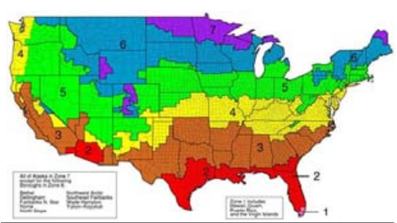

Insulation Zone	Heating System	Attic	Cathedral Ceiling	Wall: Cavity	Wall: Insulation Sheathing	Floor
1	All	R-30 to R-49	R-22 to R-28	R-13 to R-15	None	R-13
2	Gas, Oil, Heat Pump, / Electric Furnace	R-30 to R-60	R-22 to R-38	R-13 to R-15	None	R-13 / R-19 to R-25
3	Gas, Oil, Heat Pump, / Electric Furnace	R-30 to R-60	R-22 to R-38	R-13 to R-15	None / R-2.5 to R-5	R-25
4	Gas, Oil, Heat Pump, / Electric Furnace	R-38 to R-60	R-30 to R-38	R-13 to R-15	R-2.5 to R-6 / R-5 to R-6	R-25 to R-30
5	Gas, Oil, Heat Pump, / Electric Furnace	R-38 to R-60	R-30 to R-38 / R-30 to R-60	R-13 to R-15 / R-13 to R-21	R-2.5 to R-6 / R-5 to R-6	R-25 to R-30
6	All	R-49 to R-60	R-30 to R-60	R-13 to R-21	R-5 to R-6	R-25 to R-30
7 + 8	All	R-49 to R-60	R-30 to R-60	R-13 to R-21	R-5 to R-6	R-25 to R-30

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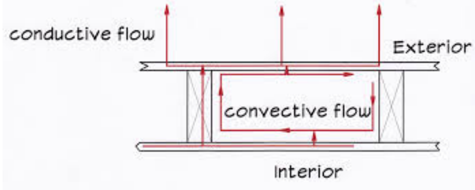

There are three forms of heat transfer in a structure: *conduction*, *convection* and *radiation*. Insulation should address all three:

- Conduction: the transfer of heat energy through matter and fluids. Conduction is the least predominant form of heat transfer in a building structure.
- Convection: the transfer of heat energy in a gas, vapor and/or air infiltration. It is most relevant where cavity insulation is concerned.
- Radiation: the transfer of heat energy by infrared rays

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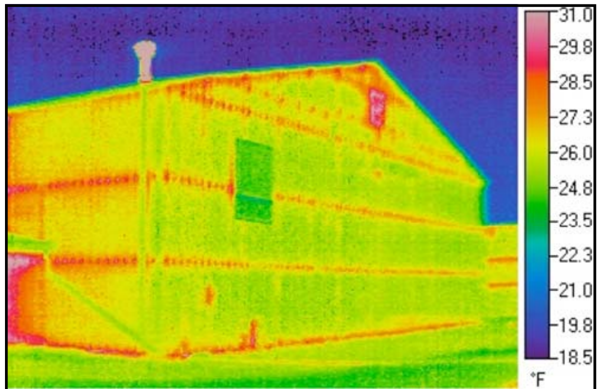

Above: caption: "This thermograph of a metal building shows how dramatic heat loss (shown in red) can be through the metal framing"

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Off the Menu

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Drywood | Subterranean | Formosan Subterranean | Queen | Worker

It might be a surprise to learn that annually, termites cause more damage to homes in the U.S. than do fires. For more than fifty years, Hawaii has suffered the scourge of the *Formosan Subterranean Termite* (FST). Native to Mainland China, Taiwan (formerly Formosa) and Japan, it was introduced into the continental U.S. after WWII by ships and their cargo. In recent years, the Gulf States (i.e. Texas, Louisiana, Florida and Alabama) and even Georgia and the Carolinas have experienced severe damage to homes and trees from these voracious termites.

Above: caption: "The most common types of termites found in the greater Houston area are drywood, subterranean (ground) and Formosan subterranean termites"

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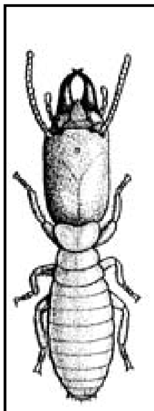

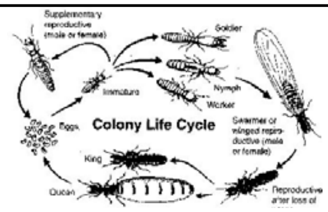

The FST forms the largest colonies of any termite species in North America. A queen can live up to thirty years with her colony in extensive underground passageways that are 10-feet deep and half-an-acre in size. A mature colony consists of up to ten million termites. The queen's long life span and prolific reproduction rate of two-thousand eggs per day provides exponential proliferation. The colony consists of a caste system of reproducers, soldiers, workers and the immature. Unfortunately, the only part of FST society that destroys wood happens to also make up the vast majority of the colony: workers. The reproducers of the colony are known as "alates." These winged termites swarm to mate in the spring and summer, shed their wings and form new colonies, thus spreading the problem far and wide.

Above: caption: "Typical subterranean termite life cycle"
Left: caption: "Soldier termites defend the colony"

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	Native Subterranean Termite	Formosan Termite
Average Colony Size	100,000 up to 1 million.	Ten million or more. The largest known single Formosan termite colony was found in a public library building in Algiers, Louisiana. The colony exceeded 70 million termites within a nest weighing approximately 600 pounds.
Aggressiveness	Moderately aggressive; a typical colony will consume about 7 pounds of wood per year. Termite shields (properly installed) are reasonably effective in helping to control. Percentage of soldiers in a typical colony is less than 2%, making them somewhat vulnerable to outside predators like ants.	Extremely aggressive; a typical colony will consume over 1,000 pounds of wood per year. Termite shields are less effective. Formosan subterranean termites will go through thin sheets of metal, mortar, PVC pipe, electric power lines and telecommunications lines to get to wood or cellulosic material. This termite will eat wood, paper, books, furniture — anything cellulosic. A typical colony has 10% to 20% soldiers and therefore is much less vulnerable to outside natural predators.
Adaptability	Moderately adaptable; more limited range; species is ground-dependent for water, making it easier to detect via mud tubes. If present in the structure, they are usually concentrated at the first-floor level. Prefers wet dead wood. Will not ordinarily infest living trees.	Extremely adaptable; not ground-dependent for moisture; can live off water condensation even at attic level. Builds carton nests in walls and roofs; carton nest serves as a satellite home, trap-ping and conserving water. Very difficult to detect in closed structures until severe damage has been done. Also attacks and causes severe damage in a broad species range of living trees; they prefer hardwoods like oak, gum and maple, but will attack softwoods including Southern Pine. Much more adaptable to varying soil types, climates, and settings — urban to the wild.
Mobility	Moderate to low; ground dependent; and relatively weak flyers in the alate (flying stage) form.	Very mobile; move around extensively when disturbed; not ground dependent. Ablates are proportionately stronger flyers.

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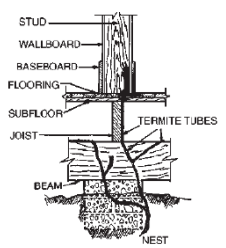

Considering the fact that most insurance companies do not cover the costs for remediation due to termite damage, avoiding the problem from the get-go makes a lot of sense. New Orleans is a good place to gauge the extent of the problem. Between 1989 and 1998, collection traps revealed an increase of 2K% in the number of alate FST's, causing an estimated $300 million in property damage annually. As a result, New Orleans mandated the use of preservative treated wood in all new construction. The FST is known to enter treated wood through cut ends and tunnel through, devouring all wood in its path. As well, they will test the limits of chemical barriers and forage tenaciously. In Hawaii, $100 million is spent annually to prevent/control/repair damage caused by the FST.

Above: caption: "An FST colony can have several million termites that can forage up to 100 meters per day"
Top Left: caption: "Typical termite shelter tubes"
Bottom Left: caption: "Termite shelter tubes on foundation wall"

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LGMF, with its HDG protective treatment, is off the menu as far as termites and other pests are concerned since it is inorganic thus indigestible to termites. Quite the opposite is true for wood, even pressure-treated wood. Termites can/do tunnel through the "heart of the wood" – the center portion where many PT applications do not penetrate. In fact, wood is at the top of the FST menu. Termite damage can/does undermine the strength/integrity of a structure. A structure needs all its members intact to resist the forces acting on it, particularly during a seismic event. With regard to termites, LGMF has great appeal as a building material, particularly where the problem is most pervasive; the Gulf and South-eastern states.

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Shake, Rattle & Roll

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Earthquakes can change the course of rivers, cause tidal waves and start devastating fires. Expanding from the epicenter, man-made structures are destroyed with ensuing loss of life. Seismic forces generate both side-to-side and up-and-down movement in the ground that is both erratic and powerful. Damage caused to structures is the result of inertia. Simply understood, inertia is the resistance of the upper portions of a structure to begin moving with the ground shifting as the result of seismic forces. Recalling our high school physics: ***"A body at rest tends to stay at rest unless acted upon by an outside force and a body in motion tends to stay in motion."*** Thus, once the resistance to moving by the upper portions of a structure is overcome by this outside force and starts to move, it wants to keep moving-not stop, not good.

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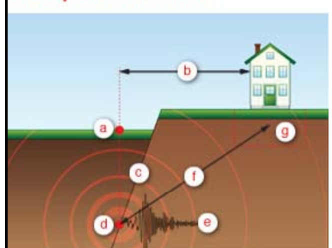
Earthquake Movements



a. Epicentre
b. Distance from Epicentre
c. Fault
d. Hypocentre/Focus
e. Earthquake magnitude
f. Distance from focus
g. Soil at the site

"Racking" is the effect caused by the inertia of the earth shifting from side-to-side, thus causing the structure to move in the opposite direction of the sideways movement of the ground. The up and down movement of the ground or vertical inertia causes two effects:
- **Compression: as the ground rises**
- **Telescoping: as the ground stops moving**

Seismic forces (left) that can/do destroy a house are produced by strong and erratic side-to-side and/or up-and-down movements in the ground. *Inertia* – the reluctance of the upper portions of a structure to begin moving once the ground has shifted and then, conversely, to stop moving once the structure has begun moving, is the cause of most structural damage to a building during a seismic event.

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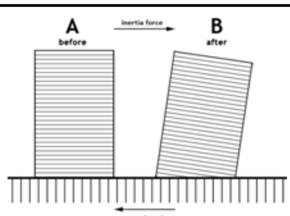

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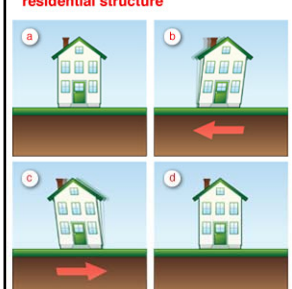
Racking motions in a two-story residential structure



a. Building at rest
b. Ground accelerates to left
c. Ground Accelerates to right
d. Ground & building at rest

Left: when the earth shifts sideways, the effect of inertia on the house is similar to that experienced by players of the game "crack the whip." If the movement is vertical, inertia causes the structure to be compressed as the earth rises and "telescoped" as the ground stops moving. Whether a house is made of wood or LGMF, the same concepts apply to the science of seismic engineering, such as:
- **Applicable building codes**
- **Engineering**
- **Design of structure**
- **Materials used for framing**
- **Quality of construction**

All play a significant part in the seismic performance of a structure. Control of lateral forces is key since it is the sliding or racking motion that causes most damage.

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Houses are designed to resist the stresses of inertia by absorbing the energy produced by an earthquake. This is typically accomplished by allowing the structure to flex with the ground movement (in varying degrees based on several factors including design, material, codes etc.). Thus, the effects of racking must be maintained at tolerable levels, limiting motion and transferring the imposed seismic loads to stiffened walls and, ultimately, the foundation. Primarily, lateral forces occur at the floor and roof levels tending to uplift or overturn walls. Therefore, it's critical to effectively tie the walls together and fasten them securely to the foundation. As well, all roofs and floors must be tied to the walls and the walls made stiff with bracing to resist lateral movement. In this way, the floors and roof between these stiff walls will effectively limit the racking of the walls and transfer the seismic loads down to the foundation.

Left: caption: "Connection of the diagonal bracing member, top chord splice, boundary members and collectors shall be designed to develop the full tensile strength of the member or sigma times the otherwise prescribed seismic forces"

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As the result of increasing earthquake activity in California, building codes for LGMF have become more stringent and the testing protocols more rigorous. Of course, tangential to earthquakes are the firestorms that multiply the misery and destruction of earthquakes, even minor ones. Since LGMF is incombustible, it does not add fuel-to-the-fire as does conventional framing lumber, which acts as kindling. Also, a wood framed structure subjected to termite infestation is weaker due to the fact that the termites literally eat the structure. Slowly but surely, this degrades the integrity of the wood framing. LGMF suffers not from this malady, maintaining its structural integrity over the entire lifecycle of the structure. Surprisingly, LGMF performs well under fire conditions. Most impressive is the fact that due to its higher strength-to-weight ratio, a LGMF structure is typically one-third the weight of the same wood framed structure. This translates into less weight, which means less inertia (less weight to stop moving). Also, LGMF uses a mechanical means of attachment; typically screws, whereas wood uses nails. Wood is subject to drying and shrinking causing warping and twisting of the framing. Since nails rely on friction and bending for holding power, as the lumber dries and shrinks the friction between nail and wood declines over time thus weakening the structure. LGMF uses a mechanical means of connecting members typically (i.e. screws) which cannot be easily undermined thus, a LGMF structure maintains its structural integrity for its entire lifecycle. Dimensional stability - a hallmark of LGMF, results in consistently straight floors, walls and roofs. Result: LGMF provides a tighter, more uniform structure better able to resist the powerful natural forces applied against it, including earthquakes.

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Incombustible

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According to the *National Fire Protection Association* (NFPA), in 2002 the equivalent of one house fire occurred every seventy-nine seconds causing 2,670 deaths and 14,050 injuries. In economic terms, more than $6 billion in property loss resulted from these 401K house fires. Part of the problem is the nature of the wood framing typically used to construct houses; it's combustible, thus it provides fuel to feed a fire and contributes significantly to the spread of the fire throughout a structure. In fact, the wood framing of a house is third on the list of "first ignited" materials in a house. Essentially, the wood framing acts as kindling and a pathway for the fire to spread.

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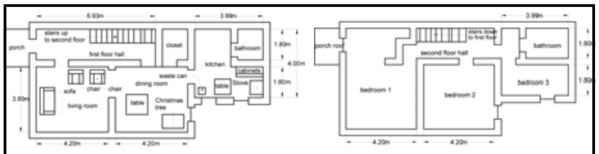
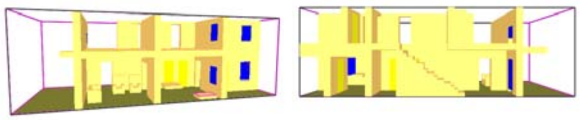
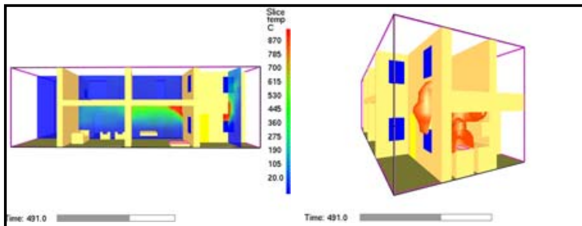


Above L&R: caption: "Plan view of 1st Floor (left) and 2nd Floor (right)"



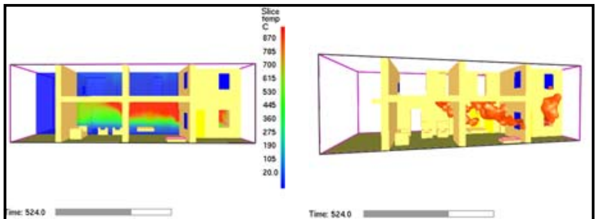
Above Left: caption: "Yard side of duplex. Outer wall removed to show living room and dining room on the first floor and front and middle bedrooms on the second floor."
Above Right: caption: "Shared side of duplex. The rear of the duplex is on the left of the figure. From the left, a bathroom, the kitchen, a closet under the stairs, the stairway and lower hall can be seen on the 1st floor. Also from the left, a bathroom, upper hall and front bedroom can be seen on the 2nd floor.

97



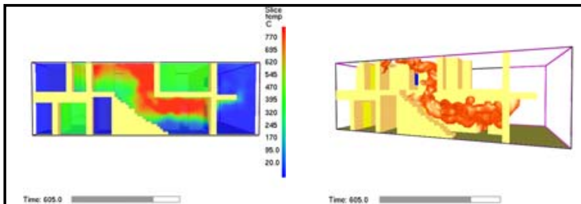
Left: caption: "Thermal conditions at approximately 8:32 AM (491 s into simulation). A distinct two-layer environment can be seen in the living and the dining room at 485 s into the simulation or approximately 8:32 AM. In the living room the upper or hot gas layer temperatures are approximately 390°F to 570°F. In the dining room the hot gas temperatures are approximately 570°F to 840°F. In both rooms, temperatures near the floor are near ambient. Gas temperatures in excess of 1,110°F can be seen near the top of the kitchen doorway and at the top of the kitchen window."
Right: caption: "Estimated flame boundary extending across kitchen ceiling and venting out of upper portion of kitchen window at approximately 8:32 AM"

98



Left: caption: "Thermal conditions at approximately 8:33 AM (524 s into simulation). Figure shows the same thermal planes, 55 s later at 540 s of the simulation. By this time, gases in excess of 1,110°F had spread across both the dining room and the living room, potentially igniting the combustible surfaces in the top portion of these rooms. Other gases, hotter than the ignition temperature of wood, are shown leaving the kitchen window and spreading up the outside of the house. This rapid change is consistent with a flashover occurring in the kitchen."
Right: caption: "Estimated flame boundary spreading through the dining room and into the living room at approximately 8:33 AM. Flames continue to spread up the outside of the kitchen."

99



Left: caption: "Thermal conditions at approximately 8:34 AM (605 s into simulation). Figure displays the plane of temperatures aligned with the center of the stairs, 1.3 ft. into the house from the shared interior wall. Approximately 600 s or 10 min into the simulation, gases in excess of 1,110°F have filled the open stairwell."
Right: caption: "Estimated flame boundary spreading through the dining room and into the living room at approximately 8:34 AM"

100

This model simulation was based on an actual fire that started on the kitchen stove. Smoke and hot gases from the fire began to spread through the house within seconds after ignition occurred. However, the simulation of the flame front indicates that the fire itself did not spread beyond the kitchen until approximately eight minutes after flaming ignition. The critical event in this fire was the onset of conditions consistent with flashover in the kitchen. At this point, approximately 8:32 AM, this fire started a transition from a single room and contents fire with smoke throughout the structure, to a fire that involved the majority of the structure within approximately 60 s. The hot gas layer temperatures in the living room increased from approximately 390°F to 570°F to more than 1,110 °F in less than a minute. The hot gases and flames continued to spread rapidly from the living room through the stairway to the second floor. This quick change in thermal conditions and flame spread through the duplex led to the deaths of three firefighters.
Top: caption: "Front of structure. Duplex on right was the unit of fire origin."
Bottom: caption: Back of structure

101

Left: caption: "Inside view of kitchen, area of origin"
Above: caption: "Dining Room with table and chairs"

102


Left: caption: "Results of fire extension from kitchen window up to rear bedroom"
Above: caption: "Rear bedroom above kitchen"

103


Left: caption: "1st floor hall with doorway to living room on left & front doorway on right"
Above: caption: "Living room with sofa from front hall doorway"

104


Left: caption: "Stairway and 1st floor hall from front doorway"
Above: caption: "Second floor landing and stairwell looking toward front of structure"

105

In a traditional "stick-built" wood frame structure, fire spreads quickly from the ignition point. In a LGMF structure, the fire is contained at the point of origin. Since LGMF is incombustible, the fire is denied the opportunity to spread rapidly from its source allowing the occupants precious time to make their escape. In a fire, seconds can make the difference between life and death.

106

In July 1996, a fire started in the kitchen of a single family LGMF home in Brentwood, California, while the owners were away. This fire became a case study for the effects of fire on a LGMF structure. Though the fire caused $75K worth of damage, there was only superficial damage to the structure. A metallurgical analysis examined both unaffected and charred studs. The result was confirmation that both-unaffected and charred framing components maintained the integrity of all their structural properties:

- **Yield Strength (YS)**
- **Tensile Strength**
- **Total Elongation**

On the charred framing components, the zinc (HDG) coating remained intact or "alloyed" (from the heat of the fire) with the base metal (steel) substrate to form a lightly iron-rich coating dubbed "galvannealed."

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Since the early 1980s, the *American Iron & Steel Institute* has been testing and developing fire ratings for load-bearing wall assemblies pursuant to the ASTM E119 standard fire test (above L&R). As a result, UL (Underwriter's Laboratory) designs include fire resistance ratings, construction and material details for such assemblies (building codes typically require LGMF assemblies to use UL or ASTM tests to achieve fire resistive ratings). Since LGMF has been used widely for many years in non-load bearing commercial interiors and curtain-wall applications, such ratings typically include the fire rating (in hours) whereby an assembly can contain the fire, smoke and heat while maintaining its integrity. In 2003 the developer of a large, multi-family residential project in California saved $400K in his builders risk insurance burden for utilizing LGMF in lieu of dimensional lumber.

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Mold Resistance

109

Whenever mold is discovered, moisture is always the main suspect. In a moisture-rich environment, mold spores feed on nutrients found in susceptible materials and grow exponentially. Whenever moisture penetrates a building envelope precipitating mold growth, there are serious consequences: lost income, health care and remediation costs, higher insurance rates and endless litigation. Mold and mycotoxins can trigger allergic reactions in sensitive individuals and even cause lung cancer. Since mold has adverse affects on *Indoor Air Quality* (IAQ), the more mold resistant the structure, the healthier the indoor environment. The mold investigation/remediation is a five-step process.

110

Step 1: Interview and Building History. Information regarding current and past problems and conditions is obtained: humidity or condensation problems, moldy odors, past or present building envelope leaks, plumbing leaks, any visible mold and health concerns and symptoms of individual occupants (health concerns and symptoms may coincide with changes in the indoor environment). The mold investigator will then narrow down the potential cause/s of the problem.

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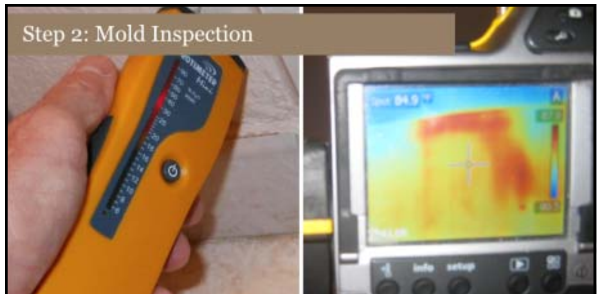

Step 2: Mold Inspection. A complete visual inspection of all accessible areas of concern is performed to locate areas of elevated moisture and other problem conditions as well as to identify any visible evidence of mold growth. Many problems are hidden within air conditioning systems, walls, floors or ceilings and are concealed from view. Specialized equipment such as moisture meters, hygrometers, borescopes, particle counters, thermal imaging cameras and laser thermometers may be used to help find those hidden problems. Thermal imaging (infrared) cameras help identify areas of elevated moisture invisible to the naked eye. Digital photography documents these problematic conditions and provides clear evidence of problem areas.

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Step 3: Mold Testing & Analysis. Mold spores in the air, on surfaces and in carpeting and upholstered furnishings can be invisible to the naked eye. Microscopic mold spores are detected by collecting samples from the air and from surfaces and analyzing them under a microscope or by culturing (growing them in a controlled laboratory environment). Typically, in addition to the inside air samples, an outdoor air sample is also collected. This is done to determine if mold spore concentrations from the indoor air are unusually high in comparison to mold spore concentrations in the outside air. The mold inspection report will include an analysis of the mold spore concentrations and type/s of species.

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Step 4: Mold Report & Protocol. A detailed written report of the inspector's findings, which may include: photo documentation, floor plans, spore levels and analysis of species (along with the inspector's conclusions and recommendations) is provided. A mold remediation protocol (which provides detailed instructions to the remediation contractor on how to perform removal and cleaning safely and efficiently) may be provided to guide the mold remediation process.

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Step 5: Post-Remediation Verification (PRV). This investigation is performed after remediation has been completed. A *Post-Remediation Verification* (PRV) survey, (a.k.a. "Clearance Test") includes a visual inspection and moisture assessment of the construction materials that were part of the remediation work. Air and surface samples are also taken for analysis. The PRV inspection is necessary to properly assess whether or not the mold remediation was performed completely and successfully and to provide a document that can be filed for future reference, should the need arise.

115

On a typical construction site, there are to be found thousands of known strains of fungus (mold) producing microscopic spores on such common surfaces as wood, paper, carpet and food. Mold exists naturally, both indoors and out, where there is an environment for it to feed on. Most conducive to mold growth are areas with excessive moisture, a sufficient food source and suitable ambient air (temperature) conditions - like the cavity of a framed wall or an air duct. Mold is a survivor and will digest whatever it grows on in order to survive and multiply. The game is about controlling its spread, not eliminating it entirely (that would be impossible). Some mold susceptible materials include many of the most common building materials:

- Gypsum board
- Oriented strand board
- Textiles
- Wallpaper glue
- Soil
- Paint

116

Paradoxically, the advancement of building technology over the past thirty years has made the indoor environment of commercial buildings more susceptible to mold than ever before. Tighter building envelopes with better thermal insulation and efficient HVAC systems meant less exchange between stale indoor air and fresh outdoor air. Though these new technologies reduced energy costs significantly, higher relative humidity levels and indoor pollutants re-circulating rather than exiting is considered to be the main cause of *Sick Building Syndrome* (SBS). To decrease high relative humidity levels, modern HVAC systems employ "desiccant" elements to absorb moisture from outside air before it enters the indoor environment. Think of the little pouch that comes with Japanese rice crackers to keep them fresh and crispy - same idea, that pouch is a desiccant material to absorb moisture.

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Left T&B: mold growing on the face of a duct register (top) and inside an HVAC duct (bottom). Infiltration of water, typically around window and door openings, roofs, foundations, plumbing, etc., is another factor in the growth of mold. Thus, the tighter the building envelope (provided with proper ventilation) the less likely mold will gain a foothold. Too often, tight buildings lack good ventilation. Uniform and dimensionally stable, LGMF consistently produces straight floors, walls and roofs resulting in better, tighter fits for doors and windows and an overall tighter building envelope than is possible with wood framing. Being inorganic, LGMF does not provide a food source for mold as does wood. A lighter and more resilient structure resists sagging and the movement that can/does cause cracks and crevices in the building envelope. Keeping moisture/water out is the first line of defense in mold resistance, denying it a food source is second. On both counts, LGMF provides the best defense. Also, LGMF is inert, thus it does not contribute to indoor air pollution in any way.

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IEQ & You

120

An advantage of LGMF concerns *Indoor Environmental Quality* (IEQ). Since LGMF is made from steel and coated with zinc, it will not off-gas any *Volatile Organic Compounds* (VOC). Most softwood framing lumber is made from southern pine. The distinctive odor of pine is derived from the release of terpenes (pine trees are the source of turpentine). Though most people are unaffected by terpenes and may even enjoy the smell of pine, other chemically sensitive people may be hypersensitive to the strong odor of pine. A condition known as *Multiple Chemical Sensitivity* (MCS) describes people with such sensitivity. Biologically, we are all unique individuals and have different tolerances and/or sensitivities. Fatigue, headaches, nausea, allergic reactions, etc., can result from exposure to certain chemical compounds. In particular, the use of synthetic materials in modern construction aggravates this sensitivity for many people. A study showed that up to 50% of all illnesses can be tracked back to the indoor environment we live and/or work in (typically, Americans spend 90% of their time indoors). That's not surprising considering the fact that the indoor environment typically contains five-to-ten times more pol-lutants than the outdoor environment and at levels of concentration up to 100x times greater.

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Another concern is the treatment of framing lumber with insecticides and the potential for off-gassing into the indoor environment. Nowadays, "healthy house" advocates use LGMF for the walls of a house to avoid entirely this potential problem. Another innovation is the use of foil-backed gypsum board throughout (not only on exterior walls as a vapor barrier). The foil backing provides a very effective vapor retarder, preventing any off-gassing that occurs within a wall cavity from entering the indoor environment. Some-times, LGMF is given a protective light coating of oil. This coating is easily wiped off prior to installation.

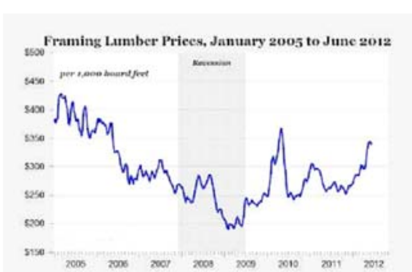
122

Price Stability

123

Though domestic steel prices have been experiencing an upsurge in recent years, it's been an increase in demand overseas that has mainly caused this situation. Normally, steel prices are very stable due to the high-recycled content and efficient manufacturing processes of the steel industry. Rather, it's the building boom in parts of Asia (China, in particular) that is causing artificially high steel prices domestically due to exports. Thinner gauge than "hot-rolled" structural steel and the omnipresent supply of scrap steel serves to keep LGMF prices stable and competitive with lumber. In recent years - and in some areas in particular, lumber prices have been highly volatile while the overall quality of framing lumber has diminished. LGMF quality is consistently superb due to precision manufacturing standards. Dimensionally stable, straight and without the scourge of warps, twists and shrinkage, the waste factor due to unusable material for LGMF is a fraction of what it is for dimensional lumber.

124



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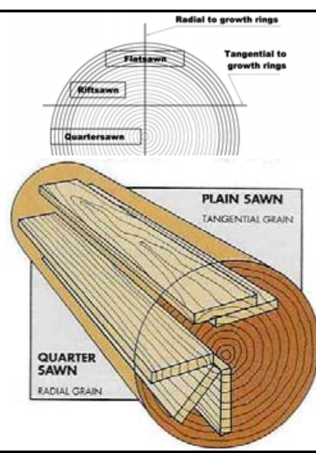

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Adaptability

128

Though it takes some getting used to, it's a fairly easy transition for wood framers to make the switch to LGMF. Industry training programs such as those offered by the ***Steel Framing Alliance*** (SFA) and innovations in tool and fastener design, equipment and a growing acceptance industry-wide have made the transition to LGMF a smooth one. In fact, LGMF has been used for commercial interiors for many years thus there's a familiarity with LGMF for many "mechanics" in the field. Price stability and the net environmental advantages of LGMF, as compared to wood, make it appealing to all concerned. However, for the house framer, it's the piece-for-piece substitution of LGMF for wood: studs, joists, rafters, etc., that makes LGMF so appealing as an alternative to wood. Add to this the superior quality of LGMF due to the manufacturing processes' exacting specifications, lightweight, dimensional stability, straightness, mechanical attachment methods and lack of defects such as twists, warps, knots, etc. (commonplace in building lumber), LGMF is very often preferred by framers with experience in both "stick-built" wood and LGMF structures thus, the familiarization period for framers unfamiliar with LGMF is very short. In fact, many framers prefer LGMF since it is lighter and more challenging. In recent years, the problems associated with penetrating floor joists for MEP (Mechanical, Electrical, Plumbing) needs has been successfully resolved with the use of steel joists with pre-manufactured openings.

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<u>Part 4</u>

Working with LGMF

132

Safety Precautions

133

Safety is an essential part of any construction project. Because of the high frequency of accidents on construction sites, safety should always be a priority. In particular, when working with LGMF, the following safety measures should always be taken:

- **Wear Work Gloves**
- **Beware Sharp Edges**
- **Use Ear and Eye Protection**
- **Use Caution Around Electrical Equipment**
- **Beware Wet Steel**

PPE (Personal Protection Equipment) such as hard hats and safety (steel-tipped) shoes should also be employed when working with LGMF.

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Wear Work Gloves

Workmen should always wear work gloves when working with LGMF. Thin gloves are recommended to allow for delicate movements such as feathering screws. Gloves serve to protect hands from:

- **Cuts and injuries**
- **Burns from steel that is exposed to and heated by direct sunlight in hot weather**
- **Burns from cold steel during the winter months**

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Beware Sharp Edges

LGMF framing members can/do have sharp edges, in particular after being cut. Thus, extreme care should be exercised when handling cut-to-length pieces. As well filings and/or scrap pieces can be dangerous and care should be taken when handling LGMF debris.

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Use Ear and Eye Protection

High-pitched noise is generated when cutting LGMF with an abrasive or metal blade which can cause hearing loss thus, ear protection is necessary if/when noise levels are higher than conversational levels. Wearing of wraparound-style safety goggles (not ordinary glasses) when working with LGMF is an absolute must, especially when cutting, because:

- **Cutting LGMF with a chop saw causes flying debris in the form of small metallic chips/filings**
- **Joining members with screws overhead increases the chance of small filings falling toward the face**

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Use Caution Around Electrical Equipment

Caution needs to be taken when handling and/or working with LGMF when around electrical equipment since:

- **LGMF members can damage electrical cords when dropped**
- **Because LGMF is an excellent conductor of electricity, LGMF should be isolated from any source of electricity to prevent electrocution hazards**

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<u>Beware Wet Steel</u>
Steel is "slippery-when-wet" thus, extreme caution should be taken when working in wet conditions (i.e. rain) and/or walking on wet steel members. As well, always exercise caution when working at heights such as on:
- **Ladders**
- **Scaffolding**
- **Roofs**

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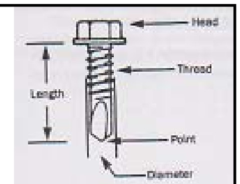
Fasteners

140

Fasteners are a critical part of LGMF. Selection of the appropriate fastener for a particular application is essential for maintaining structural integrity and keeping costs down. There have been many advancements in recent years concerning the technology for the assembly of LGMF. New screw designs, driving/cutting/joining tools etc. and on-going R&D has made working with LGMF more efficient and cost-effective than it was a generation ago. Using the correct screw for a given application is essential. If an inappropriate screw is used, an improper connection is made and failure may be the result. An understanding of the variety and differences in screw designs promotes proper selection and better/stronger connections. Typically, LGMF screws are zinc plated for corrosion protection.

141

The "pullout" (a.k.a. "withdrawal") – the ability to pull the screw out of the connection – is based on the number of threads penetrating the LGMF member, not by friction (as for nails). Thus, it's critical to select the proper screw to prevent it from stripping the hole/s made in the members being joined. Holes are not pre-drilled in LGMF framing rather, the screw itself must have the ability to make its own hole in the members being joined before the cutting threads engage. As such, screws known as "self-drilling" or, more commonly, "self-tapping" are used when connecting heavier (structural) gauge LGMF members (left). When driven into steel, this type of screw has the ability to drill a hole first and then form threads in the hole upon engaging the steel. The figure at right depicts the parts of a self-tapping screw. Each screw has a point, diameter, head, drive type, thread and plating.

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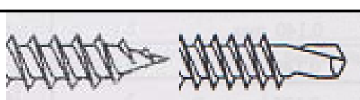

The point at the end of a screw must be sharp enough to penetrate steel. The point pre-drills the hole and allows the threads to engage the steel. Two types of points are predominantly used in LGMF:
- **<u>Self-Piercing Screws (left)</u>:**
- **Have sharp points that easily pierce thin layers of steel (18-gauge/27-mil and lighter)**
- **Traditionally used to attach panel products (i.e. plywood, gypsum wallboard) to LGMF**
- **<u>Self-Drilling Screws (right)</u>:**
- **Have drill points at the end of the screw without threads. The drill-point comes in a wide variety of lengths and styles**
- **The drill-point must be as long as the overall steel thickness to be joined to drill effectively. If the drill-point is too short, the first layer of steel will "climb" the threads (a.k.a. "jacking") instead of remaining in place while the screw penetrates subsequent layers. The screws will then either bind or break-off entirely.**
- **The higher the reference number of a drill-point, the longer the point and the thicker the steel to be drilled/joined**
- **For thicker (heavier gauge) layers of steel, longer point styles and/or thicker diameter screws are necessary**

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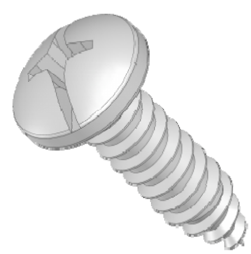


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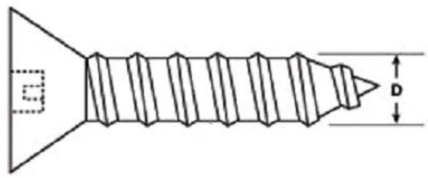

The *Diameter* (D) of a screw is the measurement from the outside of the threads on one side to the outside of the threads on the other side. The diameter provides strength in shear (resistance to forces that try to break the screw across the shaft):

- **Numbers that refer to the diameter of the screw designates screw size (i.e. No. 6 = 0.138-inch diameter)**
- **The higher the number, the stronger the screw**
- **For basic steel-to-steel connections, a No. 2 point style (for up to 3-layers of 20-gauge/33-mil steel) is adequate**

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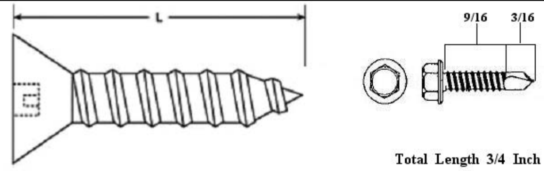

The *Length* (L) of the screw is measured from the bearing surface of the fastener head to the end of the point. Good practice requires that:

- **Screws should extend through the joined steel for a minimum of three exposed threads (3/8-inch min.)**
- **For most steel-to-steel connections, ½-inch or ¾-inch (right) screws are suitable**
- **When applying panel products to LGMF (i.e. plywood), proper screw-length is determined by adding together the measured thickness of all materials, with an additional 3/8-inch for the exposed thread requirement**

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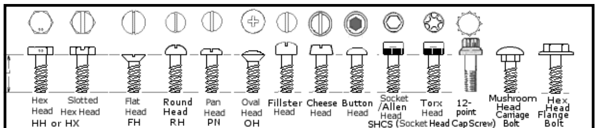

***Head* style/s (sampling above) of LGMF screws are available in a wide variety. The head locks the screw into place and prevents it from sinking through the layers of material and/or just below its surface. The head also contains the *Drive Type* (type of bit tip) to apply the screw. The following are some of the most common head styles in use:**

- **Hex Washer**
- **Modified Truss**
- **Pancake**
- **Bugle**
- **Trim**
- **Pan**
- **Truss**
- **Oval**
- **Flat**
- **Wafer**

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Head style choice depends on the specific application (i.e. type of connection required, material to be joined etc.). The most popular head/drive style for steel-to-steel connections is the *Hex Washer* type (A) since it has the most "positive" drive. If a panel product (i.e. sheathing, gypsum board etc.) is to be applied over the screw, the head style must have a very thin profile to prevent "bumps" (a.k.a. "blow-outs") at the screw locations. *Modified Truss* or *Pancake* (B) head styles are preferred for this application. When applying sheathing or gypsum board to LGMF, *Bugle* head (C) type (a.k.a. "Drywall Screws") are most common. This type of screw recesses flush with the surface forming a smooth finish face. For trim items (i.e. baseboard), small *Trim* head (D) screws are used. The small head penetrates the trim, leaving a small hole easily filled.

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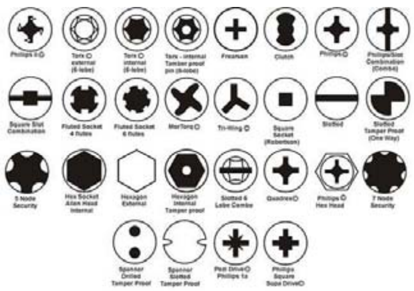
The *Drive Type* on the screw head determines the type of bit necessary to turn and drive the screw. The bit tip (sampling above) needs to turn the fastener quickly, fit securely and release quickly once the screw is driven. If the bit doesn't fit properly, it may become lodged in the head of the screw. *Philips* and *Hex Washer* head screws are the most common drive types:

- **Philips drives (left) are most commonly used with Modified Truss, Pancake and/or Bugle head screws**
- **The Hex Washer head provides the most "positive connection." A connection is the quality of the fit of the bit tip in the head of the screw. Positive connections feature no slipping and/or movement while driving the screw. Screws stay in the Hex Washer driver better than in Philips, resulting in a more positive connection. Because of this, it's recommended that Hex Washer heads be used as much as is practicable when working with LGMF.**

150



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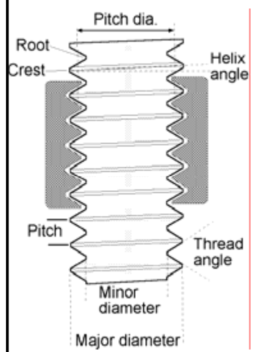

<u>Left</u>: the *Threads* of a screw cut through the steel, forming grooves that properly seat the screw. Screws have three distinct thread thickness (spacing of the threads):
- **Coarse**
- **Medium**
- **Fine**

In general, coarse screws (above) have threads spaced furthest apart for optimum cutting power are used to connect LGMF members. For heavier gauge LGMF (i.e. 12-gauge/97-mil), fine threaded screws (have threads spaced closest together) are required (below).

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Drive pins/nails are designed for use in a pneumatic (compressed-air driven) gun. They are specifically designed to penetrate steel and generally have spiral grooves on the nail shaft. Use of pneumatic nail guns (similar to those used in wood framing) can significantly increase productivity. Typically:
- **Plywood or OSB sheathing may be applied to LGMF using 1" or 1½" pneumatic pins**
- **Manufacturers provide shear strength data for wall and/or roof sheathing applications**
- **Sheathing (i.e. plywood) must be held tightly against the LGMF before the pin is driven because firing the pin does not tighten the sheathing against the steel. Roof sheathing can be installed with pins readily because the installer can use their body weight to hold-down the sheathing tight to the LGMF rafter/truss.**
- **Tacking the sheathing to the LGMF screws or screwing the perimeter first and then pinning the field tightens the sheathing against the LGMF for a proper installation**
- **Pneumatic pins/nails are used for attaching panel products (i.e. wall/roof sheathing, sub-flooring) to LGMF, not for steel-to-steel connections**

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Welding and/or clinching are two alternatives to screw attachment of LGMF components which are gaining in popularity:

<u>Welding</u>:
- **Certified welders should be employed when welding LGMF members together to meet code requirements**
- **Touching-up welded areas with zinc-rich paint to restore the integrity of the HDG coating is required when welding LGMF. The heat of the welding torch burns away the protective zinc (HDG) coating on the bare steel.**
- **Welding works best in a shop setting where the elements are not a factor and a higher level of quality control can be maintained than in the field (i.e. manufacture of panelized sections)**
- **Welding is a more permanent fastening method than screws. To remove welded members, cutting is required whereas with screws, they can be reversed out of the member/s**

<u>Clinching</u>:
- **Requires no screws or pins, only a pneumatic clincher that press-joins (a.k.a. "mechanical weld") the steel members together**
- **Manufacturers of the pneumatic clinchers provide test reports verifying the strength of the press-joining**
- **Like welding, this method works best in a shop environment. It is a less permanent fastening method of joining LGMF together than welding since the joined members may be popped and/or drilled out if correction is required.**

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Table 1: Minimum material thickness recommended for welding cold-formed steel (CFS) connections

Application	Shop or Field	Electrode	Suggested minimum CFS thickness
CFS to Structural	field	stick	54 mil – 68 mil
CFS to Structural	shop	stick	54 mil – 68 mil
CFS to CFS	field	stick	54 mil – 68 mil
CFS to CFS	field	Wire-fed MIG	43 mil – 54 mil
CFS to CFS	shop	Wire-fed MIG	33 mil

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Design Standards

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Structural Engineers use the AISI's *Specification for the Design of Cold-Formed Steel Structural Members* (left) to design LGMF residential structures. There are two methods used:

- The Performance Method: uses established engineering principles and practices to determine design loads/criteria for the calculation of LGMF member size, type, grade etc.
- The Prescriptive Method: uses pre-calculated, tabulated values to determine LGMF members based on regional design loads. This method has limitations regarding the size of the structure and/or design loads.

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The *Prescriptive Method for Residential Cold-Formed Steel Framing* was first developed in 1995 by the *NAHB Research Center.* Funding for the project was provided by:

- The *U.S. Department of Housing and Urban Development* (HUD)
- The *American Iron and Steel Institute* (AISI)
- The *National Association of Home Builders* (NAHB)

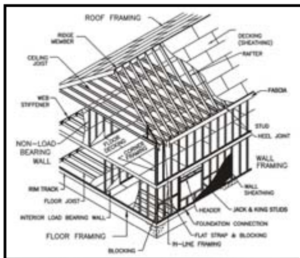
Note: consult the NAHB for the most up-to-date edition

There are several benefits when using the *Prescriptive Method* (PM), including:

- Selection of all stud, joist and rafter sizes from tables
- Building inspectors can easily check LGMF member sizes and material specifications as indicated on the drawings
- Reduces engineering costs
- 33KSI (YS) steel is used exclusively in the PM to simplify the span tables

The PM cannot be used to design all LGMF residential structures (it's most widely used in tract housing developments). Depending on the size, location etc. of the project, an engineer's services may be required to ensure that building code/s are not violated and a safe design is established. To be cost-effective, it's most advantageous to use an engineer familiar with the use of LGMF. The *Light Gauge Steel Engineers Association* (LGSEA) provides a worldwide network of engineers specializing in the design of LGMF structures.

162



<u>Top</u>: caption: "Figure 1.4 – Schematic of Typical Steel Framed Building. Figure 1.4 is provided as an overall view of residential steel framing and the basic components" (excerpted from the *Prescriptive Method for Residential Cold-Formed Steel Framing*)
<u>Bottom</u>: caption: "Home Construction Using Cold-Formed Steel Framing. A cooperative effort between industry and the U.S. Department of Housing and Urban Development (HUD) has led to the development of standard minimum dimensions and structural properties for basic cold-formed steel framing materials. The express purpose of the venture was to create prescriptive construction requirements for the residential market.

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American Society for Testing and Materials

The grades of steel typically allowed for use in residential (load-bearing) LGMF construction (per ASTM standards) are:
- **ASTM A653: Grades 33, 37, 40 and 50KSI (Class 1 and 3)**
- **ASTM A792: Grades 33, 37, 40 and 50A**
- **ASTM A875: Grades 33, 37, 40 and 50 (Class 1 and 3)**

<u>Note</u>: check with ASTM for compliance for tensile and/or elongation requirements and/or any changes to their standards/requirements
It's important that the correct grade of steel be used to support imposed loads. Most common in structural LGMF is 33KSI steel. The cold-former can/will supply:
- **Mill certificates demonstrating that the steel complies with ASTM requirements**
- **Test results verifying that ASTM standards have been met**

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The C-shape is the most common shape used in LGMF. Typically, it's used for:
- **Wall Studs**
- **Floor Joists**
- **Roof Rafters**

The C-shape member comes in a wide variety of sizes, gauges and grades of steel. The depth of a C-shape member is measured from the outside of the flange to the outside of the opposite flange. Each flange has a "lip" (a.k.a. "return"). The web is the portion between the two flanges. Most common for structural wall framing purposes is the "2 x 4" metal stud (1-5/8" flange / 3-1/2" web). In this way, metal studs have the same actual dimension as their 2 x 4 wood counterparts allowing for a wood nailer (ground) to be secured to studs (via screws). A U-shaped channel (a.k.a. "track" or "runner") is used to secure a C-shaped stud in place top and bottom (similar to the "plates" used in wood frame construction). A track is composed of two flanges and a web (no return/lip) and its depth is measured from the inside of the opposing flanges thus allowing the stud to fit in between. Starting with 8-inches, steel joists' web depth have the same nominal/actual dimension.

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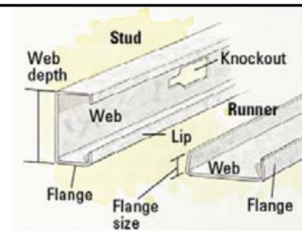

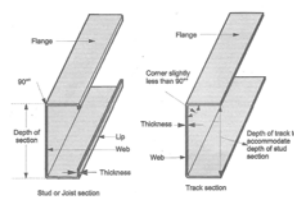

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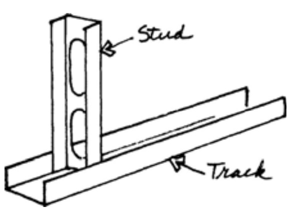

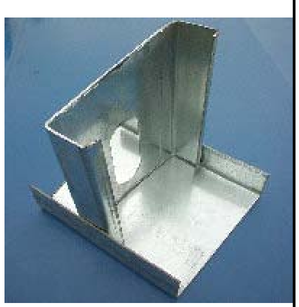

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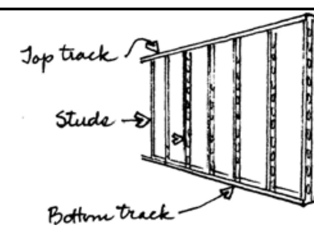

168



LGMF (as used in residential construction) can be categorized into three distinct types:
- Stick-Built (top left)
- Panelized (top right)
- Pre-Engineered (left)

169

Stick-Built

Stick-built LGMF structures are built one piece at a time on-site. The method is the same for both steel and/or wood frame construction. However, unlike wood framing, LGMF is typically spaced at 24-inches O.C. (rather than 16-inches O.C., as with wood) due to steel's higher strength-to-weight ratio. Framing methods follow wood framing practices (i.e. "tilt-up" wall panels). This is the most popular LGMF method.

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Panelized

Panelized construction uses platform tables and jigs (templates to build repetitive framing components) to build various LGMF assemblies (i.e. walls) in a controlled environment (i.e. factory). The pre-built components are then taken to the job site and installed in-place. Panels may also be built on-site (i.e. field assembled roof trusses). Panelized construction minimizes labor at the job-site which is especially beneficial when weather conditions are a critical factor.

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Pre-Engineered

This method of LGMF construction treats the component parts (i.e. stud, joist, rafter) as an individually engineered part for a specific design purpose. Pre-engineered LGMF construction may consist of a rigid or semi-rigid frame, with columns spaced four or eight-feet O.C. As well, whereas stick-built LGMF typically uses 20 or 18-gauge (33 or 43-mil respectively) members, pre-engineered LGMF typically uses 14 or 12-gauge (68 or 97-mil respectively). Spacing of members at greater intervals (i.e. 32-inches O.C.) and welding and/or clinching is typical of pre-engineered LGMF. While pre-engineered LGMF does have a niche market, it's mainly used in proprietary systems. The most commonly used pre-engineered LGMF components are roof trusses.

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Part 5

Superstructure

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An Eye for an Eye

180

"If a builder has built a house for a man and his work is not strong, and if the house he has built falls in and kills the householder, that builder shall be slain"
***Code of Hammurabi*, Babylonian Empire (2000 B.C.)**

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Foundations

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The foundation of a LGMF house has a direct impact on the integrity of the structure. The type/quality of the foundation affects the LGMF design, anchoring method and the str-aightness of the walls. A foundation not only supports the weight of the superimposed loads of the structure, it also provides a level surface to commence framing. Regardless of the type of foundation, all foundations:
- **Act as an anchor for the house, preventing damage during wind, weather and/or seismic events**
- **Serve as a platform to frame upon**

Essentially, there are three types of house foundations commonly used in residential construction:
- **Slab-on-Grade: concrete slab at grade level**
- **Crawl Space: stem walls (typically two to four-feet in height) that elevate and support the first floor**
- **Basement: floor six to eight-feet below ground with walls (typically reinforced concrete) that hold back the soil**

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As with wood frame construction, LGMF requires secure anchorage to the house foundation. Anchor devices selected are dependent on the type of foundation, wind load and the seismic zone in which the house is located. LGMF must always be anchored to the foundation properly and in compliance with local building codes. Anchors must be designed for embedment in, or attachment to, concrete. The most common anchor types are:
- **Anchor Bolts**
- **Mudsill Anchors**
- **Anchor Straps**
- **Mushroom Spikes**
- **Powder Actuated Fasteners**

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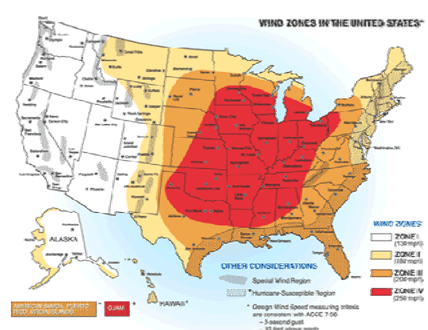

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187

Anchor Bolts

- Bolts embedded in concrete
- Includes J-bolts, L-bolts and/or threaded rods (with nuts and washers on the embedded end)
- Epoxy and/or expansion anchor bolts are also widely used in LGMF. A hole is drilled after the concrete is poured and the bolt is set in place.

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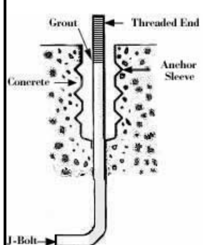

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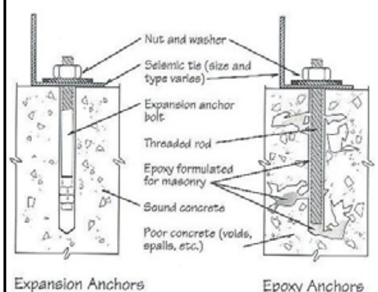

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Mudsill Anchors

- Anchors with one end embedded in concrete while the exposed end fits snugly into the bottom track to hold the wall down (left)
- They're usually available from specialty fastener manufacturers (i.e. *Simpson Strong-Tie*) or fabricated in the field

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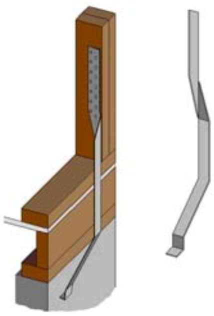

Anchor Straps

- Steel straps that are embedded in the slab and bend up to attach to the stud framing member/s of the wall (left)

193

Mushroom Spikes

- Expansion bolts that expand in pre-drilled concrete holes
- Typically used to hold-down bottom track or rim joists
- Available from specialty manufacturers

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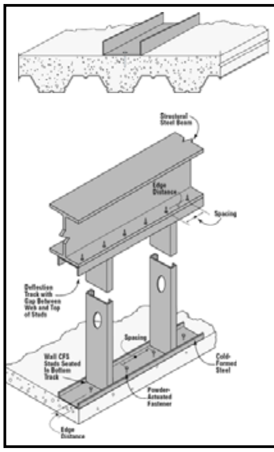

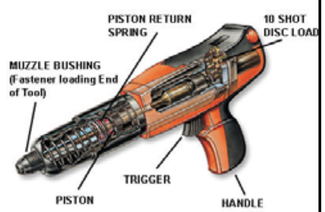

Powder Actuated Fasteners

- Pins fired by a special gun to secure the bottom track to the foundation (above)
- A.K.A. "Shot & Pin"

__Left T&B__: caption: "Typical Powder-Actuated Fastener Installation"

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Irregularities can/do occur in the top surfaces of concrete floor slabs and/or foundation walls, even in the best quality concrete/masonry finishes. If significant, these irregularities may have a noticeable and detrimental impact on LGMF structures because:

- The bottom track contours to the bumps and dips (a.k.a. "hills and valleys") in a foundation's top surface. If this surface is not level, so too anything built atop it will also not be level
- Any/all bumps should be chipped flush to the surface prior to framing
- It may be necessary to stiffen the bottom track with a nested C-shape (i.e. stud) to span a dip in the foundation wall/slab
- Use of one or more wood sill plate/s is recommended to span irregularities in the surface and to provide a level base for framing

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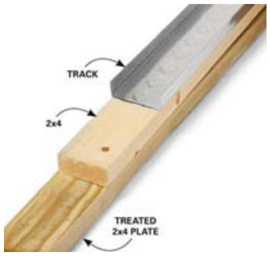

199

Floors

200

Floor joists are horizontal members that support super-imposed loads on the floor/s of a structure. The direction the joists span and the choice between a single (a.k.a. "simple") span or a multiple (a.k.a. "continuous") span is critical to the framing process.

201

Span Direction

Span direction is the orientation of the joists to the foundation. Joists can run from end-wall to end-wall or side-wall to side-wall. In many cases, a hybrid configuration is used whereby the floor plan/s are broken up into sections and the joists run in different directions in different portions of the structure. Typically, when joist size/s are selected, an assumption is made concerning span direction/s. Span direction is important because:

- **LGMF joists are designed to carry a maximum load**
- **If floor joists exceed their span limitations, the resulting floor will have a "bounce" when live loads are imposed and/or may be subject to failure**

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Floor Joist Selection

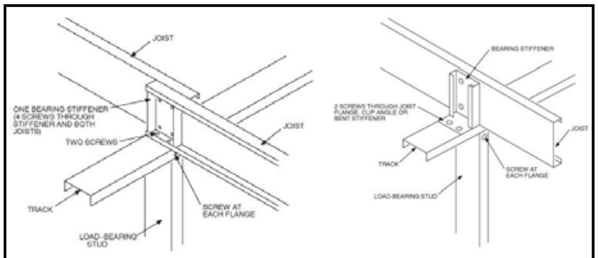
LGMF floor joists can be installed using two different methods:

- **Single Span: run from end-wall to end-wall or side-wall to side-wall without intermediate support. Two single span joists that overlap over an intermediate girder are considered single/simple span joists**
- **Continuous Span: the joists run continuously from one side of the structure to the other. If there are one or more supports (i.e. girder, beam), then the joist/s have more than one span. Therefore, they are considered to be continuous/multiple span joists.**

It's important to determine which method will be employed in advance because:

- **There are separate span tables for single and/or multiple span joists**
- **Allowable spans often differ significantly for single/multiple span joist/s for the same loading condition/s**

204



Left: caption: "Lapped Joists Supported on Stud Wall" (two single/simple spans)
Right: caption: "Continuous Joist Span Supported on Stud Wall"

205

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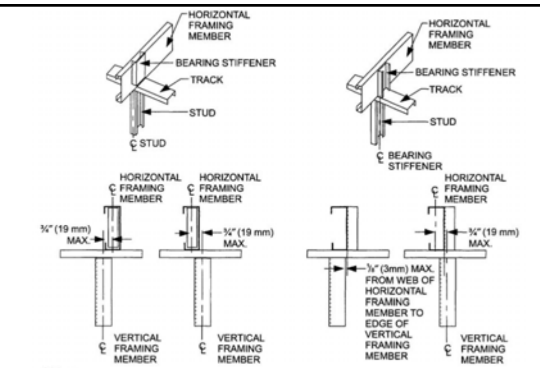
In-Line Framing

In-line framing – the alignment of all vertical and horizontal load-bearing members, is typically used/required in LGMF construction. The alignment typically begins with the roof truss/rafter layout. In-line framing is necessary in order to transfer all axial loads from the roof trusses/rafters directly through the wall studs and the floor joists into the foundation. If pre-engineered roof trusses are used, the floor joist/s location will coincide with the location of the roof trusses as laid out in the design drawings provided.

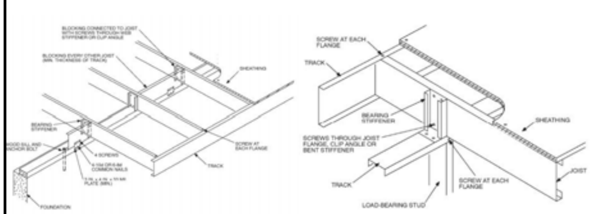
Above: caption: "Additional skill is needed when installing steel framing, as the top track is not capable of transferring vertical loads; the other framing members must be aligned vertically to transfer vertical loads"

207



Above: caption: "In-Line Framing Tolerance Limits. To qualify as 'In-Line' each joist, rafter, truss and structural wall stud must be aligned vertically according to the limits depicted here."

208

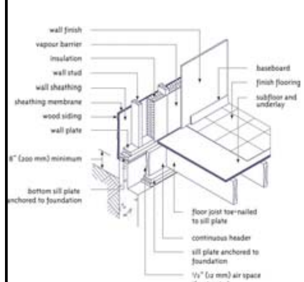


Cantilevered Joists

Cantilevered joists overhang a foundation or load-bearing wall creating additional floor space (i.e. Bay Window). In the PM, floor overhangs are typically limited to 24-inches.

Left: caption: "Floor Cantilever to Wood Sill Connection
Right: caption: "Floor Cantilever to Load-Bearing Wall Connection

209



Recessed Floor Joists

An alternative method of installing floor joists is to recess them into the foundation itself. Rather than resting the end/s of the joists on top of the foundation wall, they butt-up against the inside of the foundation wall on a pre-formed ledge (wood framing condition shown at left). In this approach, these floor joists need not line up with the wall studs/truss layout because the wall framing no longer bears on the floor joists at this level.

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Bracing

Bracing floor joists prevents the joists from rolling and/or twisting. The top flanges of LGMF floor joists are braced by the sub-floor sheathing applied (i.e. plywood, OSB). Sheathing thickness must comply with the span requirements (based on joist spacing) in applicable building codes. Based on span length, bracing the bottom flange of LGMF joists may not be required (check code requirements). If bottom flange bracing is required, gypsum board panels or steel strapping (in conjunction with blocking or bridging) may serve to brace the bottom flange/s:

- **Blocking is a solid piece of joist, stud or track**
- **Bridging is usually cross-bracing consisting of strap or pre-manufactured members**
- **Steel straps must be installed without slack**
- **Check code requirements for maximum spacing of blocking/bridging and end requirements (at straps)**
- **Check code requirements for minimum fastener requirements for attaching straps to blocking**

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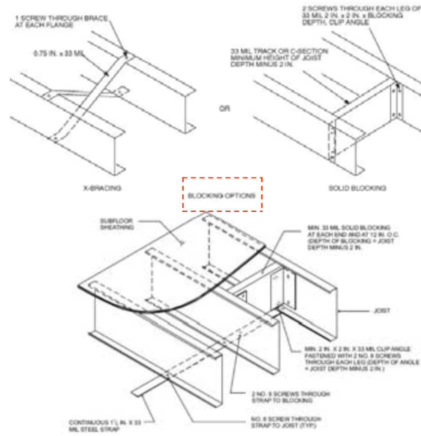

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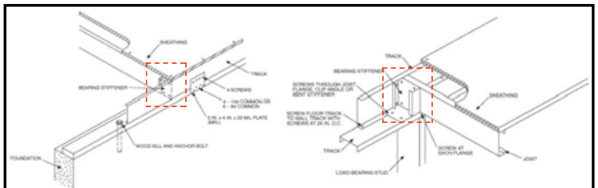
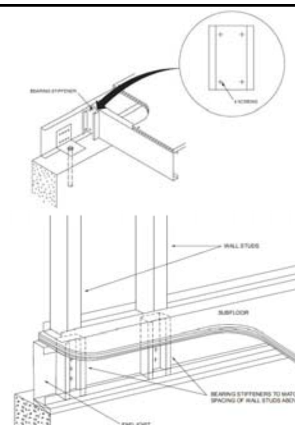


Web Stiffeners

Web stiffeners are added to joists to prevent them from crumpling under loads from axial loads applied from above. Typically, when standard LGMF floor joist/s and rim track/s are installed on top of the foundation (left) or at load-bearing walls (right), web stiffeners must be installed. Some proprietary floor joist systems negate the need for web stiffeners (the rim track provides an integral web stiffener).

Left: caption: "Floor to Wood Sill Connection"
Right: caption: "Floor to Load-Bearing Wall Stud Connection"

213



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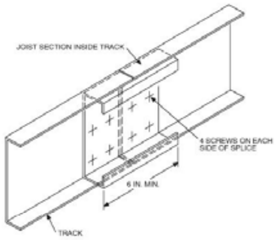

Splices

Splices (above) are necessary wherever one section of rim track is not long enough to extend the entire length of the wall (they're typically manufactured in standard stock lengths). Typical requirements for splices include:

- **Use of 6-inch minimum length joist material for the splice**
- **Use four No. 8 screws through the web or flanges on each side of the splice (check code requirements)**

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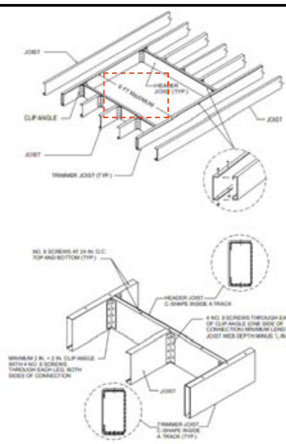
Floor Openings

Floor openings are locations where stairways or other access is provided through the floor. Floor openings should be framed with built-up header and/or trimmer joists. Typically:

- **Header joist spans less than 8-feet in length may be framed using the same size floor joists (check code requirements)**
- **Headers should be built using a "nested" member consisting of a floor joist inside a track**
- **Two-inch by two-inch clip angles (with four No. 8 screws each leg) are used to fasten headers to trimmers (check code requirements)**
- **Trimmers are built in a similar manner to headers (nested members)**

218



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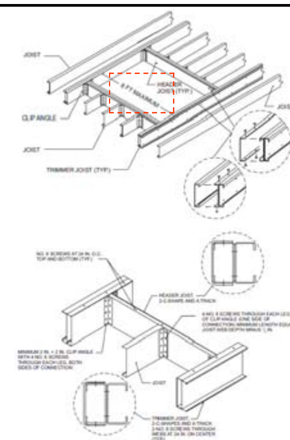

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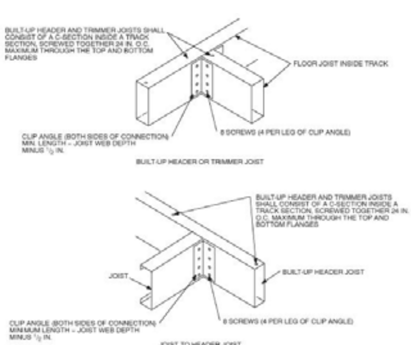

221

Sub-Flooring

Local building codes should always be consulted when determining the proper thickness of sub-flooring to be used. In general:

- **When 24-inch O.C. spacing is used, codes typically require 23/32-inch T&G (tongue & groove) APA (*American Plywood Association*) rated sheathing (plywood or OSB)**
- **Sub-floor sheathing helps greatly to brace the floor joists**
- **Sub-flooring can be screwed down with min. No. 8 bugle head screws, 6-inches O.C. along the edges and 12-inches O.C. in the field (check code requirements)**
- **Use a screw gun with an adjustable depth setting to assure that the head of the screw is slightly below the top surface of the sub-floor**

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Load-Bearing Walls

224

After the floor joists are set in-place and the sub-flooring is installed, construction of load-bearing walls may commence. These walls support the weight of the structure above and protect the structure from natural forces (i.e. wind, weather etc.). Load-bearing wall layout is controlled by in-line framing requirements. All load-bearing studs must be aligned with the trusses, joists, rafters above and/or below. Since these walls carry loads, it's important to fit each stud tightly in the track to allow the stud to properly carry the axial (downward) load from above. "Platform" (floor-to-floor walls), stick-built framing is typically used for two or three storey houses utilizing LGMF. "Balloon" (studs extend full height – from foundation to roof) framing is possible using LGMF. However, it is typically categorized as a pre-engineered system.

Above: caption: "When installed properly, steel framing effectively resists hurricanes and other types of extreme weather"

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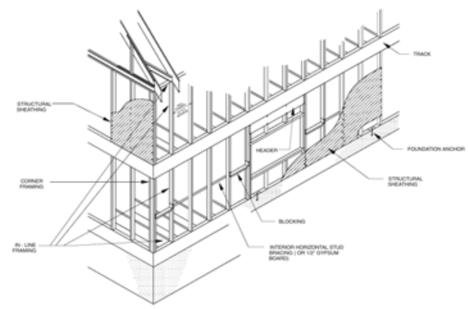

Above: caption: "Schematic of Typical Steel Framed Building"

226

Walls may be constructed on a flat surface (i.e. floor deck/slab) or on a panelization table (left). The latter provides better quality control (i.e. can be located indoors), uses assembly-line methods (thus increasing productivity) and helps the framer to build perfectly straight walls (thus minimizing plumbing and/or aligning after erection).

227

Wall Length

Walls may be framed in one of two ways:

- **Full Length: full-length walls may be framed up to 40-feet in length. This allows for walls that are straight and square and can be erected in less time. On the down-side, the longer the wall the more labor required to erect it. As well, longer walls tend to twist, resulting in damage to the framing members.**
- **Short Sections: shorter sections are easier to manhandle thus requiring less labor than full length walls. Short sections can be spliced together (including track) however, greater care must be taken to ensure that the joined sections are aligned and straight.**

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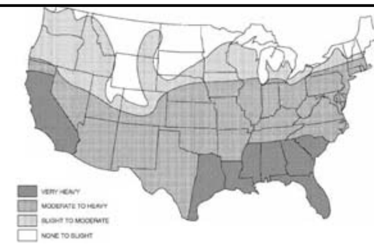


Stud Selection

Under the PM, wall stud tables are based on *Ground Snow Load* conditions. If the site is not located in a snow load region, snow load values may be interpreted as live or dead loads. Typically, the lowest ground snow load value (20 psf) is used under these circumstances (check code require-ments).

Above: caption: "Ground Snow Loads for the United States"

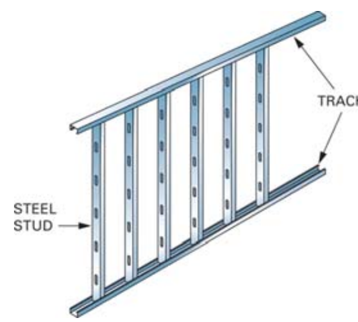
230

Considerations

Two factors should be determined before stud selection can begin:

- **Stud Spacing (O.C.): 24-inches O.C. spacing (rather than 16-inches O.C.) is usually selected for a LGMF house to conform with in-line framing requirements.**
- **Stud Size (web depth): a 3½-inch web depth (a.k.a. "2 x 4") C-shape stud is typically used in LGMF residential framing. Cavity insulation is applied in the stud cavity and over the exterior sheathing, negating the need for thicker batts. As well, this common size is readily available and mates well with dimensional lumber.**

231



232

Headers

Headers (to carry loads over wall openings such as doors and windows) are typically made up of C-shapes assembled on-site into either a "box" or "back-to-back" configuration. Each type has advantages and disadvantages in relation to one another. King and trimmer (a.k.a. "jack") studs support the header on either side of the wall opening. They are typically the same size members of the wall framing and their configuration (number of jack/king studs required) is de-termined by the size of the wall opening spanned by the header.

233

Box Header

Box (a.k.a. "Box-Beam") headers form a box configuration by fastening C-shape members (track/stud) together whereby two members (stud or joist) face one another so that the top and bottom flange lips are in close proximity. A track section is then screwed into the top flange/s of the two opposing members. In general:

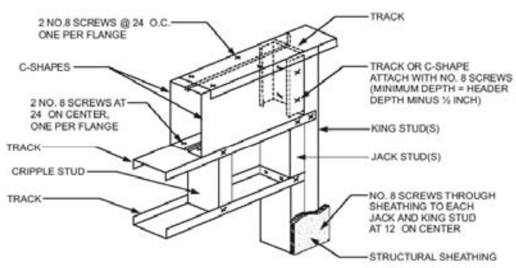
- **They are especially beneficial when anchor straps are used to anchor roof trusses or rafters. These straps typically require a flat surface to screw into which is inherent in a box header**
- **Since it is not possible to install batt insulation within the void space of the box section once the box header is in-place, insulation must be installed during assembly. This is especially important on exterior walls where failure to pre-insulate can/will result in thermal short-circuits (i.e. cold spots)**

Back-to-Back Header

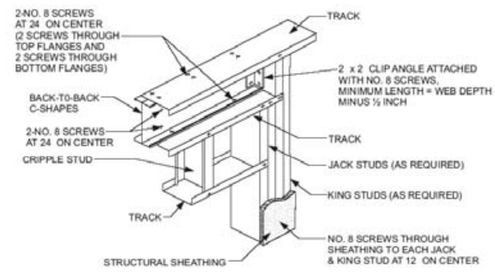
With a Back-to-Back header, two C-shape members (stud/joist) are joined at their webs and a track section is secured to the top flange/s of the opposing members. In general:

- **They are considered to be less labor intensive than box headers**
- **Since the web/s are left open on either side of the header, it can be insulated at the same time as the rest of the wall**

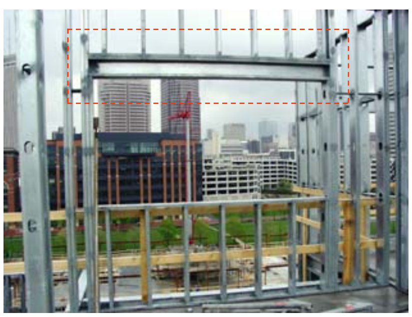
234



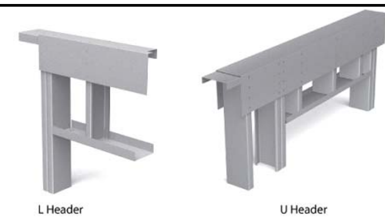
<u>Above</u>: caption: "Box-Beam Header" 235



<u>Above</u>: caption: "Back-to-Back Header" 236



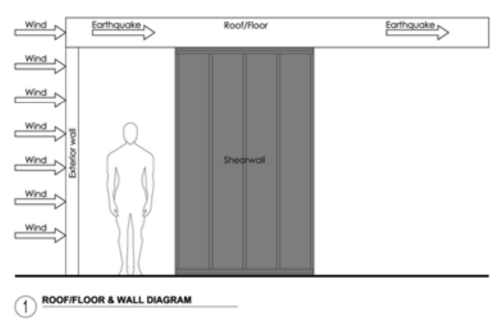
237



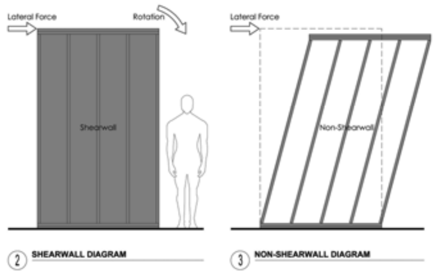
<u>L and U-Shaped Header</u>
Pre-fabricated L and/or U-shaped header/s are also used in LGMF (check code for suitability). The "L" header (left) consists of one or two angle pieces (two legs) that fit over the top track of a wall opening (the L-shape itself spans the opening) while the "U" header (right) is a composite section consisting of three legs in a U-configuration that also fits over the top track of a wall opening. As compared to Box and/or Back-to-Back Headers, L and/or U-shaped headers require less labor to install (since they are pre-fabricated elsewhere) and typically require fewer screws to install. However, they may not have the same load capacities (i.e. uplift) as Box and/or Back-to-Back headers (check code for suitability) 238

<u>Bracing</u>
Load-bearing LGMF walls must be braced to resist shear loads and prevent "racking" (a.k.a. "skew"). Typically, wall bracing includes:
- **<u>X-Bracing (a.k.a. "Tension Strapping")</u>: used to obtain shear strength when structural sheathing is not used**
- **<u>Structural Sheathing (i.e. plywood)</u>: provides shear force resistance and prevents racking (wind speed, seismic zone and wall opening percentages must be taken into consideration)**
- **<u>Intermediate (strapping and blocking)</u>: used when framing is left exposed on one or both sides**
- **<u>Temporary</u>: for both panelized and/or erected walls – typically plywood is applied to one side to prevent racking of framing members**
- **<u>Internal</u>: prevents twisting (torsion) – CRC shape run through knock-outs (at pre-determined vertical intervals) and secured to each stud**

239



<u>Above</u>: caption: "The diagram Above shows a simple roof/floor and wall relationship. When wind or earthquake forces are applied to the house, the floors and roofs want to move sideways. In order to keep those roofs and walls right where they're supposed to be, a sturdy connection to a shearwall below is required." 240

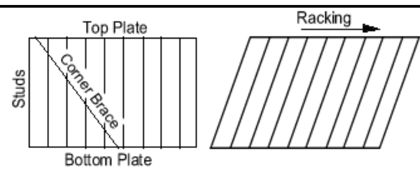


Above: caption: "Getting the lateral force from the exterior walls to the roof or floor and into the shearwall is only one step in the sequence, though. Once the forces are distributed to the shearwall, the integrity of the shearwall itself becomes an important factor. The diagram to the left shows how a shearwall resolves the applicable lateral forces applied to it. The connections between the framing members and the sheathing (plywood) creates a wall member that works as one element. Without the sheathing, the wall fails to act as one member and the individual connections between framing members fail under the same lateral forces as in the diagram above to the right.

241

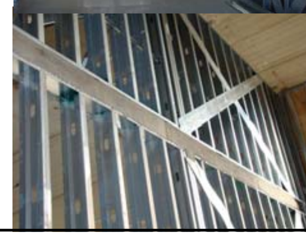
Left: caption: "When the shearwalls of a project are inadequate (or absent) and cannot resolve the load of the shifting weight above due to lateral forces, it can result in something like the image at left".

242



The corner brace intersects both the top and bottom plates. Without the cormer bracing, the wall on the right can "rack" or "skew" when the bottom plate is nailed and cannot move and the top is subjected to a force (wind).

243



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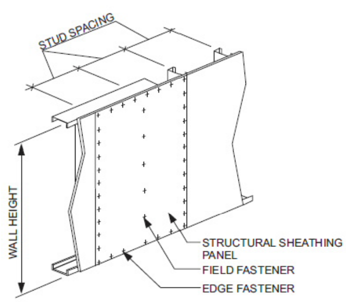

Above: caption: "Structural Sheathing Fastening Pattern." Assuming there are not excessive openings in the load-bearing wall, Type II Plywood or OSB is usually sufficient to prevent racking. Also, check code requirements for wind and seismic force resistance requirements. Structural sheathing is required to cover the full height of the load-bearing wall – from top track to bottom track.

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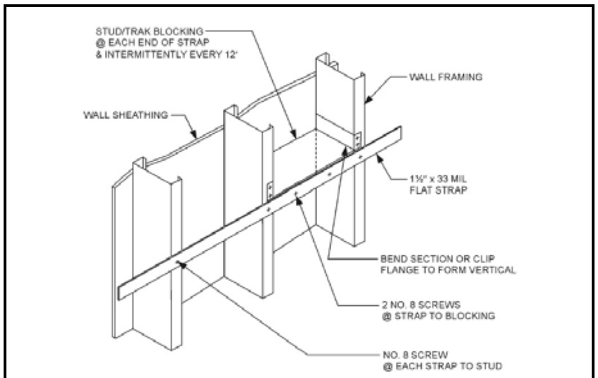
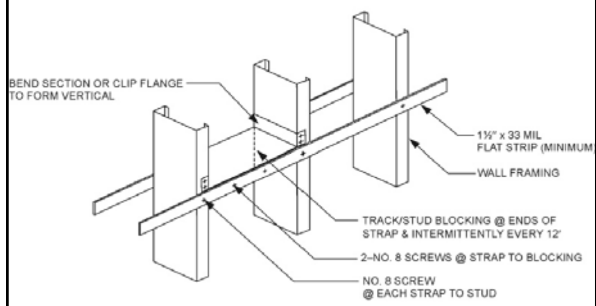
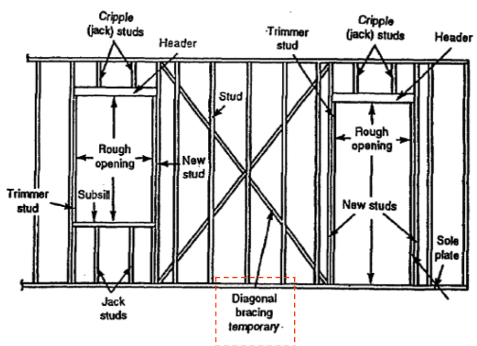
246



Above: caption: "Stud Bracing with Strapping and Sheathing Material" 247



Above: caption: "Stud Bracing with Strapping Only" 248



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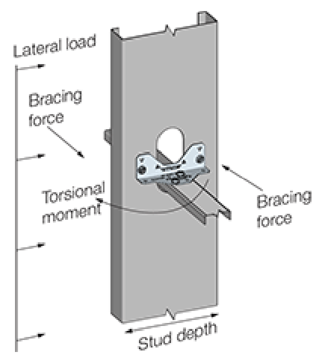
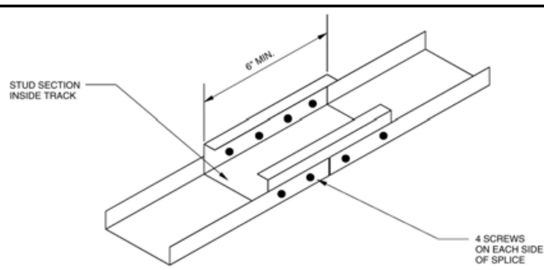


250



Splicing

Load-bearing wall studs should not be spliced without an approved engineering design. On the other hand, wall track will need to be spliced since it is manufactured in standard stock lengths (10-feet, typical). Splices (above) should not be located within three-inches of the wall studs and/or anchor bolt locations. 251

Non-Load Bearing Walls

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After all load-bearing floors, walls and roof members are fastened in-place and properly braced, the installation of non-load bearing walls may commence. Typically, these are the wall assemblies that divide rooms from one another (a.k.a. "demising partitions"). Since such walls do not support any axial loads, in-line framing is not necessary nor is the use of structural quality LGMF components required. Typically referred to as "Drywall Framing," non-structural sizes are similar to structural C-shapes, but are of a non-structural gauge (i.e. 25-gauge/18-mil). Very often, framers will use 20-gauge/33-mil non-structural studs for non-load bearing walls for additional strength, particularly at door/window jambs. Typically, non-structural studs have a 1-1/4-inch flange (rather than 1-5/8-inch) and a G40 (rather than G60) HDG coating. Deflection (bending) Limits (DL) apply based on wall height, spacing, gauge, web depth and finish surface/s.

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Roofs

255

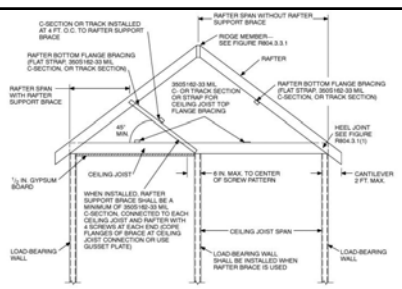
After the load-bearing walls are erected and properly braced, roof framing can proceed. Essentially, there are two approaches to using LGMF for roof framing:

- **Stick-Built: uses C-shaped roof rafters**
- **Panelized: uses pre-engineered/fabricated truss members**

Each type has its advantages/disadvantages in relation to one another:

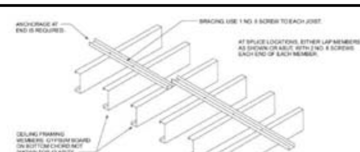
- **Roof rafter framing (with minimal support bracing) provides more usable attic space than trusses**
- **It usually takes longer to frame rafters than it does to set trusses**
- **Rafter framing typically requires less steel than trusses thus, fewer steel members equates to fewer connections which decreases labor costs**
- **Since rafters are framed in-place, the framers must work from scaf-folding and/or ladders for a longer period of time**
- **Complex roof designs are more easily achievable with rafter framing since it is more adaptable to field conditions whereas trusses work best when there is much repetition**

256

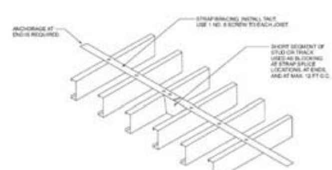


Above: caption: "Steel Roof Construction." The figure above shows a cross-section of a house with roof rafters. Two rafters rest on the top track on each side of the house, coming together as a ridge member at the top. The weight of the roof and any additional load is carried through the rafters to the top track and down the wall studs. The ceiling joist spans across from one side of the house to the other, tying the two rafters together. Screws tie the bottom flange/s of the ceiling joist/s to the top track of the bearing wall and hold down the roof framing (check code requirements for uplift connector/hold-down clip requirements). The ceiling joist also prevents the walls from spreading outwards because of the weight imposed by the rafters. Rafters and ceiling joists are usually spaced 24-inches O.C. for LGMF houses. Collar beams are typically not required (check code requirements)

257

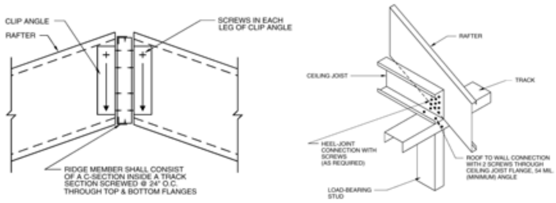


Above: caption: "Ceiling Joist Top Flange Bracing with C-shape, Track or Cold-Rolled Channel"



Above: caption: "Ceiling Joist Top Flange Bracing with Continuous Steel Strap and Blocking

258



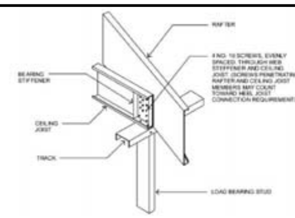
The main difference between wood and LGMF rafter framing are:

- **LGMF has a different ridge detail**
- **LGMF rafters rest on the outside edge of the top track – no "Bird's Mouth" cut-out (notch) is allowed as in wood rafter framing**

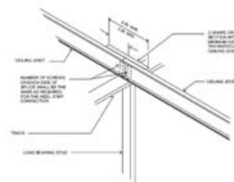
The ridge member is made from a C-shaped member (stud/joist) nested inside a track section (akin to a header/trimmer) of the same size/gauge as the rafter/s and is typically attached (via screws) with 2x2-inch angles, also the same gauge (or greater) as the rafter (check code requirements). Roof rafters are set at the roof pitch of the structure. Snow loads and spans must be considered when determining LGMF rafter size/gauge.

Left: caption: "Ridge Member Connection"
Right: caption: "Heel Joint Connection

259

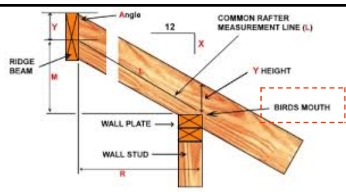


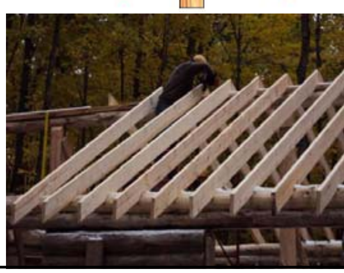
Above: caption: "Bearing Stiffener"



Above: caption: "Spliced Ceiling Joists"

260





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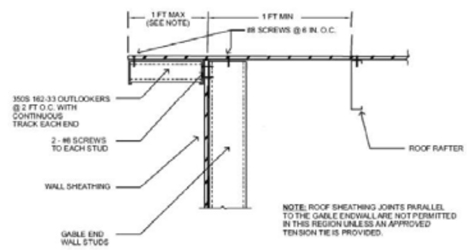
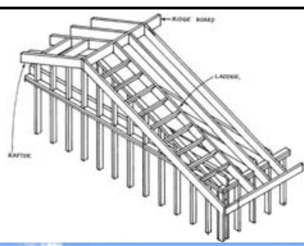


Roof Rake

The rake of a roof is the portion that extends beyond the walls on the gabled ends. Rakes often consist of plywood extending over the edges of the roof. *Barge* rafters (rafters on the outside of the structure) and *Outlookers* (24-inch O.C. framing from the gable end to the Barge rafter) are a popular method of creating a roof rake. They can be framed in place or pre-fabricated in ladder-like sections

Above: caption: "Gable Endwall Overhang Details"

262



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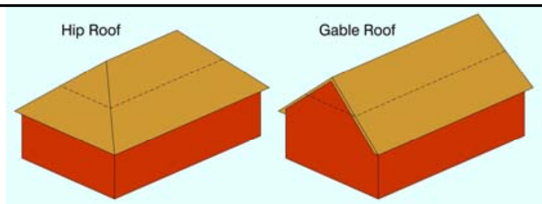
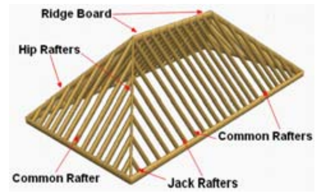


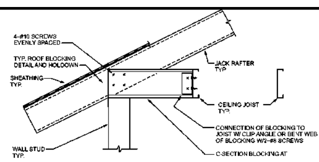
Hip Roofs

Hip roofs (left) are used to break-up a roof profile. Rather than keeping the same roof slope from one end to the other (i.e. Gable roof) the roof slopes towards each end of the structure (thus eliminating gable ends). In may parts of the U.S., Hip roofs are very popular. However, they are more complicated to frame than gable roofs since they introduce edges that slope towards each end of the structure. Step-down trusses can be used to frame a Hip roof, but Jack rafters are more popular being similar to rafter framing. This entails installing hip rafters from the peak of the intersecting ridge to the top plate corners (the tail of the rafter typically extends over the top plate). Jack rafters fill-in the rest of the framing.

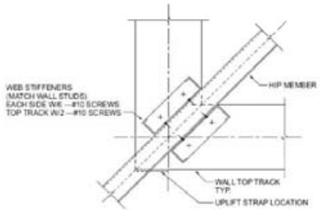
265



266

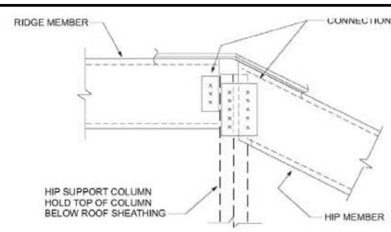


Above: caption: "Jack Rafter Connection at Eave"

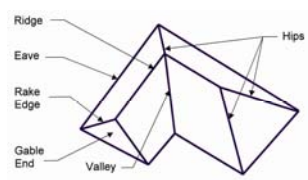


Above: caption: "Hip Member Connection at Wall Corner"

267



Above: caption: "Hip Connections at Ridge"



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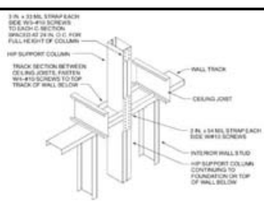
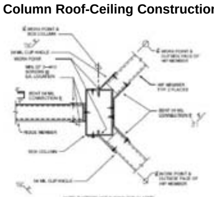


Above: caption: "Hip Support Column Roof-Ceiling Construction"



Above: caption: "Connection at 5½-inch Box Column"

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Above: caption: "Step Down Hip System, Plan View"

Above: caption: "Step Down Hip System, Rendering"

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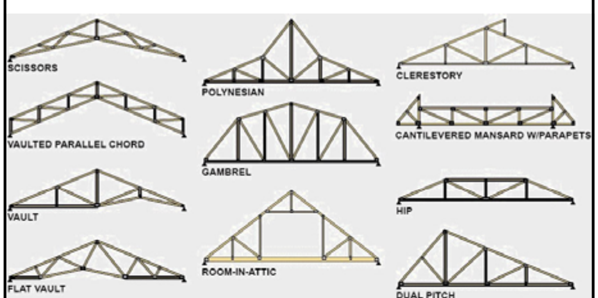
Roof Trusses

Trusses are engineered structural triangular frames that, when assembled according to design, effectively carry their own weight and any superimposed loads. As with rafter framing, all load-bearing walls need to be in-place and properly braced before erecting roof trusses. Roof trusses are:

- **Pre-engineered**
- **Assembled by a truss fabricator in their facility or by a contractor on the job site**
- **Typically span the entire width of the structure**
- **Are typically spaced 24-inches O.C.**
- **Can be installed faster than roof trusses**
- **May eliminate the need for load-bearing interior walls due to their long spans.**

Job-site fabrication of trusses is more labor intensive, typically requiring the setting-up of a jig (template). On the other hand, pre-fabricated trusses provide one-stop shopping: engineering, shop drawings, fabrication, transportation and even installation. Even if the trusses are site-built, engineered drawings are required by local jurisdictions. Site assembled trusses typically use standard C-shapes and use screws for fastening whereas the controlled environment of a fabricating shop allows for more sophisticated joining (i.e. welding), use of a wider variety of framing components (i.e. 4-inch members) and greater quality control than is practicable on a construction site. Truss members should be un-punched (no voids such as knock-outs, as in standard C-shapes). Such holes can/will weaken the truss at critical points. As with roof rafters, bird's mouth cut-outs are not allowed in any type of truss – pre-fabricated and/or field assembled.

272



Above: caption: "Roof Truss Types"

273

Truss Bracing

Truss bracing is important to protect the frame from collapse during construction, especially in high wind conditions. Braces provide rigidity and help prevent a "Domino Effect" collapse of installed trusses. Multiple, lateral cross braces (consisting of continuous LGMF angles) are typically used for this purpose. No more than four trusses should be set in-place at one time without bracing and bracing should proceed as work progresses.

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