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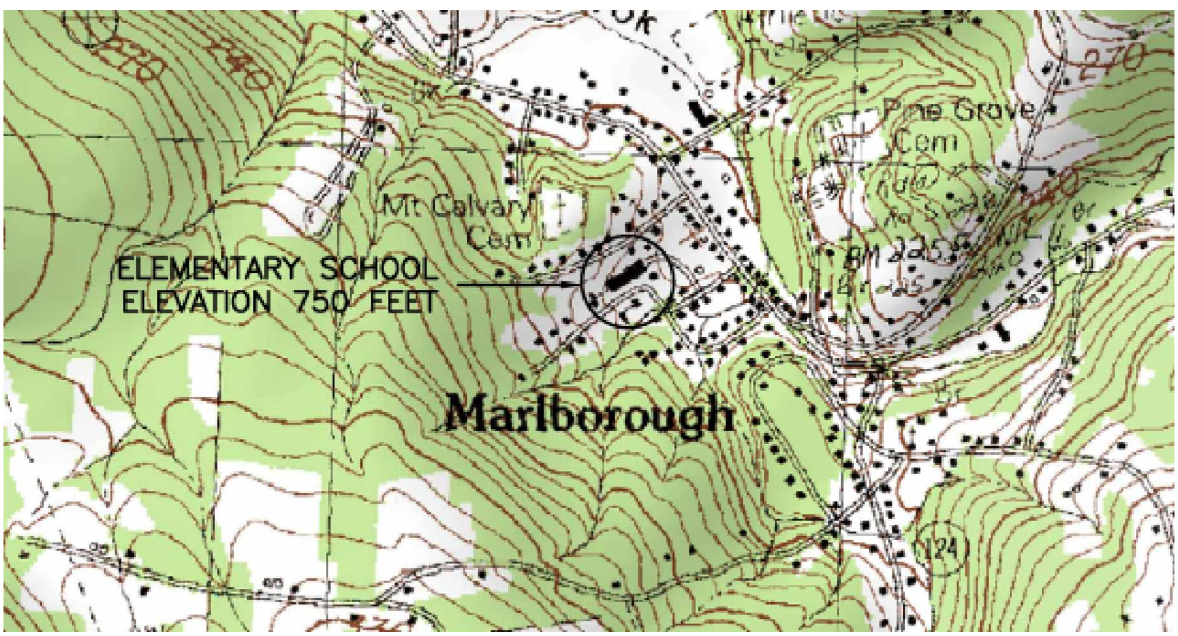
MARLBOROUGH ELEMENTARY SCHOOL FLAT ROOF SYSTEM ENGINEERING REPORT

REPORT DATE: December 12, 2006
PROJECT NUMBER: 194

CLIENT: Weller & Michal Architects, LLC
222 West Street
Keene, NH 03431

PROJECT: Flat Roof System
Marlborough Elementary School
23 School Street
Marlborough, New Hampshire

INSPECTION DATES:	November 8, 2006	November 13, 2006
TIME:	3:00 PM	3:00 PM
WEATHER:	Sunny, 50 degrees	Cloudy, 50 degrees



TOPOGRAPHIC MAP SHOWING SCHOOL LOCATION AND ELEVATION

EXECUTIVE SUMMARY

Weller & Michal Architects Inc. contracted with GV Engineering, LLC (GV) to perform a structural inspection and assessment of the flat roof system of the Marlborough Elementary School for gravity loads. These inspections encompassed inspecting the flat roof from access holes in the ceiling of the school as well as performing a visual inspection of the flat roof from the exterior.

The current applicable structural code is the New Hampshire State Building Code. The current State Building Code incorporates IBC 2000 by reference. Because New Hampshire is likely to adopt a more current version of IBC, GV believed it was prudent to use the most current IBC which is IBC 2006. Throughout this report when referring to the current code reference to IBC 2006 is intended.

GV's assessment and opinions are based on limited field inspections. GV did not observe any conditions which are indicative of persistent overstressing of the structural roof members. GV's observations, made from the interior and the rooftop of the building, did not indicate any significant deflection. GV's calculations of the existing roof rafters for the current code required gravity loads indicates overstressed conditions of 54% and 22% respectively for original building and the addition using conservative presumptive wood species and grading.

GV recommends that the actual allowable stresses be more precisely determined through a visual inspection of the lumber and opinion of the grade by a certified inspector and by sending samples of the lumber to a materials testing laboratory to determine actual strengths. If the grading and testing indicate that the existing rafter strengths do not meet current code a number of actions could be taken to bring the flat roof system into compliance with the current code. Any corrective action of the roof system to accommodate increased loads should not be taken without evaluating the ability of other components of the structure to also handle the increased loads.

BACKGROUND

Weller & Michal Architects Inc. contracted with GV Engineering, LLC (GV) to perform a structural inspection and assessment of the flat roof system of the Marlborough Elementary School for gravity loads only. The original Marlborough Elementary School was constructed in 1957. In 1964 there was an addition to the school.

The scope of the work included inspecting the existing flat roof system, providing schematic drawings of our findings and performing engineering load calculations to determine the current load capacity of the system. GV was also asked to comment on whether the flat roof system meets current code requirements and if applicable make recommendations regarding methods to bring the flat roof system into compliance with current codes. GV was also asked to comment on whether the existing flat roof system met code requirements at the time of construction,

NARRATIVE

GV inspected the Marlborough Elementary School flat roof system on November 8, 2006 and November 13, 2006. These inspections encompassed inspecting the flat roof from access holes in the ceiling of the school as well as performing a visual inspection of the flat roof from the exterior. The following are our observations and conclusions. Attached are photographs and drawings which provide further context and detail as to our findings.

The inspections were performed by removing ceiling tiles in the rooms noted on the drawing and making observations in the area. The approximate locations of the access holes are shown on the drawing. From each access point GV was able to view the entire length of one bay between the rafters. Photographs were taken in each bay. Representative photographs are shown at the end of this report. In some instances GV was also able to look perpendicular to the spans at the bottom edge of the rafters. Please see photographs 7 and 11. In addition to the field observations GV reviewed the photographs electronically to determine if there were any inconsistencies with the direct field observations. No inconsistencies were found.

In the areas where observations were made beyond the bay in which the ceiling tiles were removed no inconsistencies were noted.

CONSTRUCTION AND MATERIAL

The attached drawing shows the limits of the 1957 building and the 1964 addition and details our findings concerning the existing flat roof framing system. The rafter types are shown as different hatched areas on the drawing.

The flat roof rafters in the 1957 construction are nominal 2x14s with actual dimensions of 1-1/2”x13”. The rafters are spaced at 16” on center and span approximately 23’-4”. For calculation purposes GV conservatively considered the material to be # 1 Hemlock-Fir. However, it may very well be another type of wood with a higher strength. At the bearing walls between the rooms the members butt end to end. This results in a bearing on the wall of approximately 4”. Please see photograph 8.

The flat roof rafters in the 1964 section of the building are nominal 3x14s with actual dimensions of 2-1/2"x13". The rafters are spaced at 16" on center and span approximately 26'-0". For calculation purposes GV conservatively considered the material to be # 1 Douglas Fir. However, it may very well be another type of wood with a higher strength. At the bearing walls between the rooms the members overlap ends. This results in a bearing on the wall of approximately 8". Please see photograph 9.

GV calculations reflect current wood design values from the 2005 addition of the National Design Specification for Wood Construction. The design values at the time of construction of the building were likely higher than those of today. This is generally because of the changes in the physical properties of the older growth wood that would have been harvested at the time of the construction verses newer growth wood which is harvested today. Historical design values are difficult to correlate with current codes, because the design values not only reflect the strength of the wood, but also other factors considered in developing the code and the calculation methods.

OBSERVED DEFLECTION

In an unloaded condition significant deflection can be an indication of either overstressing beyond the elastic limit of the members or of a permanent deflection caused by long term loading within the elastic limits. This long-term deflection is known as "creep." A consistent pattern of excessive deflection would be an indication of inherent structural deficiencies.

Observations made from the interior of the building did not indicate any significant deflection. The approximate deflection measured in room 214 and was found to be ¼". Observations were also made on the exterior of the building on the flat roof. These observations were made shortly after a significant rainfall. If there was a consistent pattern of excessive deflection it would have been indicated by ponding of water on the flat roof at the mid-span of each bay. While there was a minimum amount of ponding noted there was no pattern observed. The most significant ponding was found to be ¾" deep. GV cannot comment on why there may have been ponding in this particular area, but it is not necessarily an indication of any structural deficiency.

The attached photographs show the lack of a pattern of ponding and also show the isolated areas where ponding is occurring. Please see photographs 1, 2 and 3.

OBSERVED CHECKS AND CRACKS

In several locations GV observed "checks" in the timbers. Please see photographs 12 and 13. Check cracks in the wood result from the expansion and contraction of the material and from the normal drying process and are not necessarily a result of overstressing. Where found, all of these checks were observed to be at approximately mid-depth of the rafters. Please see photographs 9 and 12.

In GV's opinion the observed check cracks have little or no effect on the strength of the rafters. Any cracking resulting from overstress would have been exhibited on the bottom edge of the rafters. GV did not observe any cracks on the bottom edge of the rafters. Another indication of cracking resulting from a structural deficiency would be the presence of significant deflection. As noted above GV did not observe any excessive deflection.

APPLICABLE CODES

The New Hampshire State Building Code references IBC 2000. However, the New Hampshire State Building Code Review Board will likely be recommending to the legislature that the 2006 version of IBC be adopted as the State Building Code with applicable amendments. Sometime in 2007 the newer Codes are expected to be formally adopted and become law. For this reason GV considered it to be prudent to use IBC 2006, which is referred to as the current code throughout this report.

IBC Chapter 34 on existing structures does not require the upgrading of building to keep up with changing code requirements unless there are additions, alterations, repairs and/or change of occupancy. Chapter 34 goes on to explain that if additions, alterations or repairs to an existing structure increase the force in any existing structural element by more than 5%, the structural element must now comply with new construction requirements.

The applicable code at the time of the 1957 and 1964 construction was most likely BOCA.

LOADING

The current code flat roof loads include snow (including drifting), water ponding, dead load and live load. These loads are detailed below.

Snow Load

The snow load is determined from a case study produced by the U.S. Army Corps of Engineers. This study provides a base snow load for Marlborough, New Hampshire of 80 lb/ft^2 at a reference elevation of 1,300 feet. The Marlborough Elementary School is at an elevation of 750 feet. The base snow load can be reduced by 2.1 lb/ft^2 for each 100' below the base elevation. This results in a site specific ground snow load of = 68.5 lb/ft^2. The Code provides for the following adjustment of snow load

Flat roof Snow Load = $P_f = .7(C_e*C_t*I*p_g)$

C_e	= Exposure Factor	= 1
C_t	= Thermal Factor	= 1
I	= Importance Factor	= 1.1
p_g	= Site specific ground snow load	= 68.5 lb/ft^2

Based on the above the flat roof snow load is 53 lb/ft^2 = P_f.

A very small portion of the roof is subject to a drifting snow load which has not been evaluated in the calculations.

The 1964 BOCA specified a design snow load of 30 psf in the absence of other specific information. Current code requirements result in a design snow load of 53 psf which is 76% higher than the 1964 BOCA value.

Rain Load

The flat roof of the elementary school contains drains which are designed to carry water from the roof. The roof has a 4" pitched curb around the perimeter to direct water away from the perimeter and toward the drains. A rain load results in the event that the flat roof drains are unable to carry the water from the roof. This would be the case if the become plugged with debris or ice. In this event the water could build up to a 4" depth at which point it would drain over the perimeter curb of the building. The potential load resulting from this buildup of water is shown below and is detailed in the calculations.

Rain Load = 21 lb/ft^2

Dead load

The dead load is composed of the weight of the materials used in the construction of the roof, ceiling and the fixed mechanical systems supported by the roof. This load includes the weight of the roof membrane, insulation, sheathing, rafters, ceiling strapping, cross bracing, original ceiling, new drop ceiling (where applicable), lighting and roof drains. The dead load also includes the weight of the rooftop ventilation equipment. Generally this equipment is located near the hallway and not over the long span areas. This equipment is very low weight and the weight is well distributed by the roof sheathing over a number of rafters. The impact of this load is very small, but none-the-less considered. The total dead load is shown below.

Total Dead Load = 17 lb/ft^2

If sprinklers are added in the future this dead load may be increased. It would depend on the type of system (wet or dry) on how much of an increased load the existing roof would experience.

Live Load

The live load includes the loading resulting from normal activities on the roof. These would generally only include maintenance activities. This load, by code, is noted below.

Live Load = 20 lb/ft^2

Load Summary

	Typical (lb/ft$^{2)}$
Snow Load	53
Rain Load	21
Dead Load	17
Live Load	20

Load Combinations

The current code allows for the following load combination to be used in calculating stresses in roof rafters.

Dead Load + maximum of (live, snow or rain load)

Load Combination = 70 lb/ft^2

BENDING STRESS
The bending stresses result from the bending induced by application of the above noted current design loads. The maximum bending stresses are found at the bottom of the rafters at mid-span. Overstresses would be exhibited by splitting at the bottom edge of the rafters at mid-span and would result in permanent deflection. These stresses are typically the highest stresses which a member experiences and therefore are the controlling stresses dictating rafter size and spacing. The calculated bending stresses in the existing rafters from applications of the above loads are shown below. The allowable stresses, by code, and the difference between the calculated and allowable are also shown.

BENDING STRESSES (for P_f = 53 lb/ft^2)

	1-1/2" x 13" Rafters (lb/in^2)	2-1/2"x13" Rafters (lb/in^2)
Calculated	1,791	1,338
Allowable	1,160*	1,101**
Difference	54% over allowable	22% over allowable

* Based on Hem-Fir 2005 NDS values
** Based on Douglas fir 2005 NDS values

If snow load specifications which were likely applicable at the time of construction were used the calculated stresses in the 1-1/2" rafters would be 4% higher than the allowable stresses and the stresses in the 2-1/2" rafters would be 18% lower than the allowable stresses. It should be noted that if wood design values and calculation methods likely applicable at the time of construction were used the allowable stresses for both the 1-1/2" and 2-1/2" rafter may have been higher.

SHEAR STRESS
The shear stresses result from the application of the above noted loads. The maximum stresses are found nearest to points of support of the members. Overstresses would result in splitting and failure of the rafters at these points. Typically these stresses are not the maximum stresses seen by the member and therefore are not the stresses controlling the rafter size and spacing. The calculated shear stresses in the existing rafters from application of the above detailed loads are shown below. The allowable shear stresses, by current code, and the difference between the calculated and allowable are also shown.

SHEAR STRESSES (for P_f = 53 lb/ft^2)

	1-1/2" x 13" Rafters (lb/in^2)	2-1/2"x13" Rafters (typical) (lb/in^2)
Calculated	83	56
Allowable	173	207
Difference	52% under allowable	73% under allowable

DEFLECTION

Deflection results from application of the loads noted above. Minimal deflection results from the dead loads and equipment loads. Larger deflection results from the maximum loads which are generally intermittent and for a short-term duration. From a structural perspective deflection is generally not important in and of itself, but is primarily important due to its influence on adjacent building components. The deflection limits, as specified in the code, are established to limit damage to adjacent ceilings and walls or mechanical equipment supported by the rafters. The allowable deflection, by code, and the difference between the calculated and allowable are shown below.

SNOW LOAD DEFLECTION

	1-1/2" x 13" Rafters (in)	2-1/2"x13" Rafters (in)
Calculated	1.13	1.21
Allowable *	1.17	1.30
Difference	3% under allowable	7% under allowable*

* SL Allowable for roof members supporting non-plaster ceilings = member length/240

TOTAL LOAD DEFLECTION (DL + Maximum of LL/SL/RL)

	1-1/2" x 13" Rafters (in)	2-1/2"x13" Rafters (in)
Calculated	1.50	1.61
Allowable **	1.55	1.73
Difference	4% under allowable	7% under allowable

** TL Allowable for roof members supporting non-plaster ceilings = member length/180

CREEP

In addition to the temporary deflection noted above, under sustained loads wood members exhibit time dependent permanent deformation know as creep. This usually develops at a slow but persistent rate over long periods of time. Creep becomes significant after cumulative loading of 10 years has been imposed on the members. The cumulative loading condition has not been reached and therefore creep has not been incorporated in the deflection calculations.

SUMMARY

As noted at the beginning of this report GV did not observe any conditions which are indicative of overstressing of the structural roof members. It should be noted that GV's assessment and opinions are based on limited field inspections. However, there are no indications that the limited field inspections are not fully representative of the overall conditions. As detailed above the bending stresses induced by the current code specified loads are potentially as much as 54 % higher than those allowed by the current code. The shear stresses and deflections do not appear to be controlling design issues.

It would be useful to obtain the field inspection notes upon which the previous H.L. Turner Group report was based. This would allow GV to confirm their observations relative to the damaged rafters and excessive deflection.

Although history has proven the adequate performance of the existing flat roof system, from an engineering standpoint the current codes have been thoughtfully and scientifically developed to accommodate probable loading conditions which a structure may be subject to and therefore should take priority over historical performance. The historical record of performance of the system may not be an adequate measure of its ability to perform in the future. Compliance with current codes may not be required, but may be prudent, particularly in a governmental, public building such as a school especially if that building is used as an emergency shelter.

RECOMMENDATIONS

The determination of whether the current flat roof system meets current codes for gravity loads is dependent on the strength of the rafters. As indicated above GV's calculations were based on conservative values of allowable stresses. The actual allowable stresses can be more precisely determined through a visual grading of the lumber by a certified inspector and by sending samples of the lumber to a materials testing laboratory to determine actual strengths.

GV contacted the Northeastern Lumber Manufacturer's Association (NELMA) concerning having an inspector grade the existing lumber. NELMA indicated they could definitively identify the species and provide an opinion of the grade of the lumber. An estimate cost for this would be in the range of $ 900.00 which includes the cost of the inspection, the cost for GV to oversee the inspection and perform calculations based on the results of the inspection and submit a supplemental report.

In addition to obtaining an opinion of the lumber grade samples from the existing rafters could be obtained and submitted to a laboratory for structural testing. GV recommends taking 3 samples from each of the two different types of rafters. The samples would need to be approximately 2” x 2” x 3’ long. These samples could be obtained from near the ends of the existing rafters in areas where there are very low stresses. Prior to removing the samples the beams would be reinforced with ¼” x 4” x 4’ long steel plates bolted to each side of the rafters from which the samples would be removed. These plates would be placed 2” up from the bottom of the rafters thus providing space to cut out the lower sample portion of the rafter. With the reinforcement noted above there is no concern related to a reduction in strength or durability of the existing rafters from which the samples would be taken. The samples would be taken in areas with low stresses and the proposed reinforcing will more than accommodate the strength loss resulting from removal of the sample.

Given the small cost of the inspection and testing described above compared to undertaking renovations at the school, GV recommends that both the inspection and testing be performed.

If the grading and testing indicate that the existing rafter strengths do not meet current code a number of actions could be taken to bring the flat roof system into compliance with the current code for gravity loads. These include the following:

1. Reinforcing a number of the existing members with steel plates. These steel reinforced rafters working in conjunction with adjacent unreinforced rafters would reduce the stresses in the existing rafters to levels allowed by the current code. Please see attached drawing.

2. Replacing the entire flat roof system with another flat roof system using higher strength structural members;

3. Building a gabled roof system over the current system;

4. Building a pitched roof system over the existing system.

Options three and four will also increase the building height and area and thus increase the lateral wind loading and thus may not be practical.

It should be noted that any corrective action of the roof system to accommodate increased loads should not be taken without evaluating the ability of other components of the structure to also handle the increased loads as would be required by Chapter 34 of the IBC.

If you have any questions or comments concerning this document please do not hesitate to contact our Office.

Very truly yours

GV Engineering, LLC

Carl Goldknopf, P.E.
President

Attachments: Photographs, drawings

CC: AW, File

REFERENCES

International Building Code 2000 (IBC 2000)

International Building Code 2006 (IBC 2006)

Ground Snow Loads for New Hampshire February 2002
US Army Corps of Engineers
Cold Research and Engineering Laboratory

National Design Specification (NDS)
2005 Edition
American Forest and Paper Association
American Wood Council

ASCE Standard 7-05
Minimum Design Loads for Buildings and Other Structures

Timber Construction Manual 1974
American Institute of Timber Construction

PHOTOGRAPHS

PHOTO 1 - FLAT ROOF - NOTE NO PATTERN OF PONDING

PHOTO 2 - FLAT ROOF - NOTE NO PATTERN OF PONDING

PHOTO 3- FLAT ROOF - NOTE NO PATTERN OF PONDING

PHOTO 4 - TYPICAL VIEW OF 1-1/2 x 13 RAFTERS LOOKING FROM OBSERVATION OPENING DOWN THE BAY (Room 207)

PHOTO 5 - TYPICAL VIEW OF 1-1/2 x 13 RAFTERS LOOKING FROM OBSERVATION OPENING IN OPPOSITE DIRECTION FROM ABOVE (Room 207)

PHOTO 6 - TYPICAL VIEW OF 1-1/2 x 13 RAFTERS LOOKING DOWN THE BAY FROM OBSERVATION OPENING

PHOTO 7 - TYPICAL VIEW OF 1-1/2 x 13 RAFTERS LOOKING FROM THE OBSERVATION OPENING PERPENDICULAR TO SPAN

PHOTO 8 - TYPICAL END CONFIGURATION OF 1-1/2” x 13” RAFTERS

PHOTO 9 - TYPICAL VIEW OF 2-1/2 x 13 RAFTERS LOOKING FROM OBSERVATION OPENING DOWN THE BAY (Room 211)
NOTE OVERLAPPING BEARING CONDITION OF 2-1/2x13 RAFTERS

PHOTO 10 - TYPICAL VIEW OF 2-1/2 x 13 RAFTERS LOOKING FROM OBSERVATION OPENING DOWN THE BAY - OPPOSITE DIRECTION FROM ABOVE (Room 211)

PHOTO 11 - TYPICAL VIEW OF 2-1/2 x 13 RAFTERS LOOKING FROM THE OBSERVATION OPENING PERPENDICULAR TO SPAN (Room 211)

PHOTO 12 - TYPICAL (WHERE FOUND) CHECK IN 2-1/2” x 13” RAFTER

PHOTO 13 - TRANSITION FROM ROOM 217 TO ROOM 218
DIRECTION OF SPAN CHANGES

PHOTO 14 - VIEW OF RAFTER BAY IN HALLWAY

PHOTO 15 - VIEW OF RAFTER BAY IN HALLWAY

DRAWINGS