Comments on the
Public Hearing on Blasting at the Oak Park Quarry March 29, 2016
Deerfield Township

By
Lawrence W. Gubbe, Ph.D., P.E.
Forensic Engineering Services, Inc.
7848 Bavaria Road
Victoria, MN 55386

I. Introduction

On Tuesday, March 28, 2016 Dr. Roxanne Engelstad made a presentation regarding the effect of blasting at the Oak Park Quarry on St. Paul's Liberty Lutheran Church (Liberty Church) which is located at 3512 Oak Park Road. Dr. Engelstad's presentation was made on the behalf of St. Paul's Liberty Lutheran Church located at 3494 Oak Park Road, Deerfield, Wisconsin. Dr. Engelstad described damage to the church, education building located on the opposite side of Oak Park Road from the church and to the cemetery that she alleged was caused by blasting in the quarry. She showed photographs of damage to the church that she attributed to blasting consisting of spalling of the masonry in a region two to two and one-half feet above the ground surface and a vertical crack in the limestone masonry. Damage to the education building consisted of separation of a taped joint in the gypsum wallboard ceiling and damage to the cemetery consisted of lateral shifting and tilting of some of the tombstones.

Dr. Engelstad stated her opinion that damage to the church, education building and cemetery by vibration generated by blasting could be prevented only if the maximum peak particle velocity (PPV) at the church is limited to a maximum of 0.12 inches per second (ips). She cited a number of references that she claimed supported her opinion. However, I am concerned that the misapplication of these sources has led to the erroneous conclusion that limiting the PPV to a maximum of 0.12 ips is required to prevent damage to the church.

Dr. Engelstad's profile summary in the University of Wisconsin Engineering Directory states that: *"Professor Engelstad's areas of interest are structural dynamics, vibrations, solid mechanics and mechanical design. Her research topics have included nonlinear vibration and stability analysis of piping components due to flow-induced excitations."* However, there is no indication that she has any training, experience or expertise in structural engineering or in evaluating the effect of ground borne vibration on buildings. All of which are necessary in order to develop a reasonable limit on vibration at the church which will not only protect the church from even cosmetic damage, but will allow the Oak Park Quarry to continue to produce the aggregates needed to construct and maintain infrastructure in the surrounding area.

Early in her presentation Dr. Engelstad stated: *"And, I will note here that continuous vibrations are generally more damaging than transient vibrations."* However, two out of three publications and/or standards cited as bases for the proposed limit on PPV at the church are applicable only to rail and highway traffic which not only generate long duration vibrations that occur hundreds or thousands of times a day but occur over a period of several decades. With respect to the one standard

published by the California Department of Transportation (CALTRANS, 2004)[1] which does discuss blasting as the vibration source, she not only cites the most fragile class of structure as being representative of Liberty Church but doesn't accurately describe CALTRANS recommendation for dealing with historic structures. These items will be commented on in more detail elsewhere in this review.

In addition to references, Dr. Engelstad also cites several examples of structures for which extremely low vibration limits were established by the governing authorities. However, in every case, the source of the vibration was construction activity (i.e., pile driving with a vibratory hammer) or vibration generated by rail or highway traffic all long-duration or continuous vibration; not short-duration, transient vibration generated by blasting which is at issue here.

The recommendation for limiting the PPV at the church to 0.12 ips is based on incorrectly applied references and examples that don't accurately reflect Liberty Church or the nature of the ground borne vibration at the church. In addition, the study reported by the USBM in RI 8507 was dismissed because the subject buildings were *"in generally good condition."* Which is not the case, because many of these dwellings were more than 40 or 50 years old in 1980 and had many pre-existing cracks. Furthermore, the ability of vibration generated by blasting at the Oak Park Quarry to shift tombstones on their bases can be shown to be physically impossible by application of the basic principles of physics and dynamics that Dr. Engelstad should have learned as a college freshman, if not in high school.

Each of the incorrectly applied standards used to support the recommended limit on PPV at the church are treated in detail in the following paragraphs.

II. Reference Standards Cited by Dr. Engelstad

Dr. Engelstad cited three reference standards in support of her opinion that the vibration limit at Liberty Church should be set at 0.12 ips. They are Wiffin and Leonard (1971),[2] the Federal Transit Authority (FTA, 2006)[3] and the California Department of Transportation (CALTRANS, 2004). Both Wiffin and Leonard (1971) and FTA (2006) deal only with vibration generated by rail transit systems. However, CALTRANS does deal with transient vibration generated by blasting as well as long duration vibration generated by construction and traffic. Each of these references cited by Dr. Engelstad is treated in the following paragraphs.

---

[1] CALTRANS (2004) – *"Transportation- and Construction-Induced Vibration Guidance Manual,"* California Department of Transportation, Environmental Program, Environmental Engineering, Noise, Vibration, and Hazardous Waste Management Office

[2] Whiffin, A C and Leonard, D. R. (1971) *"A Survey of Traffic Induced Vibrations,"* Transport and Road Research Laboratory (TRRL), Wokingham, Berkshire United Kingdom

[3] FTA (2004) – *"Transit Noise and Vibration Impact Assessment,"* Office of Planning and Environment, Federal Transit Administration

a. Wiffin and Leonard (1971), *"A Survey of Traffic Induced Vibrations,"*

As the title of this publication clearly states this reference deals with traffic induced vibrations, which are not only characterized by long durations but are repeated hundreds, if not thousands, of times a day over a period of decades. This is clearly an inappropriate and misleading reference to apply to vibrations generated by blasting which are transient, short duration vibrations that occur a handful of times a year.

b. FTA (2006) *"Transit Noise and Vibration Impact Assessment"*

As the title of this reference also clearly implies, this reference deals with vibrations generated by transportation, in this case rail based transportation systems. Again, the vibrations in question are not only characterized by long durations but are repeated hundreds, if not thousands, of times a day over a period of decades. This is also clearly an inappropriate and misleading reference to apply to vibrations generated by blasting which are transient, short duration vibrations that occur a handful of times a year.

c. CALTRANS (2004), *"Transportation- and Construction-Induced Vibration Guidance Manual"*

CALTRANS (2004) has been superseded by CALTRANS (2013)[4], however, with respect to vibration caused by blasting there is no significant difference between the two editions of the manual. In any event, the table produced by Dr. Engelstad is presented as Table 19 on page 27 of CALTRANS (2004). This table is preceded by the following two paragraphs:

> *"As shown in Chapter 6, there is limited consistency between the categorization of effects and damage thresholds; however, it is apparent that damage thresholds for continuous sources are less than those for single-event or transient sources. It is also apparent that the vibration from traffic is continuous and that vibration from a single blasting event is a single transient event; however, many types of construction activities fall between a single event and a continuous source. An impact pile driver, for example, continuously generates single transient events. As a practical matter and based on the nature of available criteria, the criteria can only be reasonably separated into two categories: continuous and transient.*
>
> *To assess the damage potential from ground vibration induced by **construction equipment**[5], a synthesis of various vibration criteria presented in Chapter 6 has been developed. This synthesis of criteria essentially assumes that the threshold for continuous sources is about half of the threshold for transient sources. A vibration*

[4] 2013 CALTRANS *"Transportation and Construction Vibration Guidance Manual,"* California Department of Transportation, Environmental Program, Environmental Engineering, Noise, Vibration, and Hazardous Waste Management Office

[5] Emphasis by author

amplitude predicted using Eqs. 9–12 can be compared the criteria in Tables 19 and 20 to evaluate the potential for damage."

Therefore, recommendations are applicable only to transient vibration generated by construction equipment, as clearly stated by CALTRANS (2004), not to transient vibration generated by blasting.

In addition, Table 19 lists three categories of historic buildings as shown on the slide presented by Dr. Engelstad. for the purpose of applying Table 19 to Liberty Church. Dr. Engelstad has placed Liberty Church in the most vulnerable category of "*Extremely fragile historic buildings, ruins, ancient monuments.*" However, only a licensed structural engineer with experience in evaluating and predicting the effect of ground borne vibration on buildings is qualified to make this determination.

Furthermore, CALTRANS does not make recommendations with respect to specific limits of PPV for historic buildings as stated by Dr. Engelstad. Instead, both CALTRANS (2004) and CALTRANS (2013) state (CALTRANS, 2004, pp 60 and CALTRANS 2013, pp 79):

"Special care should be taken when blasting in close proximity to historically important structures. Such structures are usually of older, less competent construction, and lower vibration limits for them are often justified. These should be addressed on a case-by-case basis."

This recommendation is reasonable and is applicable to Liberty Church; however, the sensitivity of Liberty Church with respect to vibration generated by blasting at the Oak Park Quarry can be assessed only by a structural engineer who is both knowledgeable in the area of vibration caused by blasting and experienced in assessing the effect of vibration on buildings.

III. Examples Presented to Support the Proposed Limit on Blasting Vibration

The examples that supported limiting the maximum PPV to 0.12 ips included descriptions of four historically important structures for which the maximum allowable vibration was determined to be significantly lower than the vibration damage threshold established by the USBM. These are the stone arch at the entrance and the de la Montaña Mausoleum in the Cypress Lawn Cemetery in Colma, California, the St Louis King of France Catholic Church in St. Paul, Minnesota and the Shiloh Baptist Church in Columbus, Ohio. In each of these cases, the damage criterion is developed for exposure of these structures to continuous vibration generated by traffic and construction not short-term transient vibration that is typical of blasting. Each of these example structures is discussed in more detail in the following paragraphs.

a. Cypress Lawn Cemetery, Colma, California

Two structures in the Cypress Lawn Cemetery in Colma, California were discussed in the presentation. These are the stone masonry arch at the entrance to the cemetery and the de la Montaña Mausoleum. The Cypress Lawn Cemetery was founded in 1892 and both the stone arch and the de la Montaña Mausoleum were determined to be structures with significant historical import. In addition, the de la Montaña Mausoleum because of its tall, relatively thin

spires and its deteriorated state due to lack of maintenance, was determined to be in relatively fragile condition.

The Cypress Lawn Cemetery is located relatively near a new subway link to the Los Angeles International Airport that was being constructed by Bay Area Rapid Transit (BART)[6]. The maximum vibration at the cemetery was generated by driving piling with a vibratory hammer. No blasting was conducted in the vicinity of the cemetery. The maximum allowable vibration for each of these structures was established at 0.08 ips to protect the structure from the effect of long-duration vibrations generated by driving piling with a vibratory hammer.

These limits were established for long-duration, vibration generated by construction activities and are not comparable to short-duration, transient vibrations generated by quarry blasting.

Furthermore, Dr. Engelstad stated that the stone masonry arch at the entrance to the Cypress Lawn Cemetery was constructed of granite masonry, whereas Liberty Church is constructed of limestone masonry. She implied that because granite has "*about twice the compressive strength of limestone*" the stone arch was substantially stronger and less vulnerable to vibration damage than Liberty Church. However, stone masonry typically fails as a result of failure of the mortar in the joints or the bond between the masonry units and the mortar. Therefore, the strength of the mortar and the strength of the bond between the mortar and the masonry units controls the strength of the structure. Failure through masonry units typically occurs only when a masonry unit lies on a failure path mapped by joints above and below the masonry unit in the case of a vertical crack or to both sides of the unit in the case of a horizontal crack. Therefore, comparison of the compressive strengths of granite and limestone bears little relevance to the overall strength of the structure.

b. Shiloh Baptist Church, Columbus, Ohio

The Shiloh Baptist Church in Columbus, Ohio is located near the interchange of I-70/71 which was under construction in 2009 and 2010[7]. The church was reportedly constructed in 1920 and is constructed of brick masonry. The construction activities nearest the church consisted of drilled shaft installation approximately 50 feet from the church and pile driving for the construction of a bridge located approximately 200 feet from the church. The maximum allowable PPV was established to be 0.12 ips based on the Swiss Standards.

As in the previous case, the limit on vibration established for this church was established for vibration generated by construction activities (i.e., pile driving and drilled shaft construction) and are not applicable to short-duration transient vibrations generated by quarry blasting.

---

[6] Wilson, Ihrig & Associates, Inc, et al, (2012), "*Current Practices to Address Construction Vibration and Potential Effects to Historic Buildings Adjacent to Transportation Projects*," NCHRP 25025/Task 72

[7] Harris, Miller, Miller and Hanson, Inc., (2009), "*Technical Memorandum - Construction Vibration Impact Assessment at Site 1 – Shiloh Baptist Church - I-70/I-71 South Innerbelt Corridor Project – Columbus, OH*," FRA-70-8.93 PID 77369

c. St. Louis King of France Catholic Church, St. Paul, Minnesota

In 2008 the Metropolitan Council of the seven county Minneapolis/St. Paul metropolitan area conducted a study of the impact of vibration generated by a proposed light rail, rapid transit line linking downtown Minneapolis with downtown St. Paul, Minnesota[8]. The rail line would pass down Snelling Avenue near the St. Louis King of France Catholic Church in St. Paul and is referred to as the "Green Line". The study considered the potential effect of rail traffic on the church.

Green Line trains operate 24 hours a day, seven days a week. Trips operate every 10 minutes throughout the day, every 10-15 minutes during evenings and every 30-60 minutes overnight. This means that approximately 100 trains a day, each generating long-duration vibration pass the St. Louis King of France Catholic Church on a daily basis, 365 days a year over a project service life of more than 50 years. It is this vibration that was the subject of the Metropolitan Council's study and precipitated in the establishment of

The effects of long-duration vibration occurring 100 times a day, 365 days a year over a period of more than 50 years are not applicable to the transient vibration generated by quarry blasting that occurs a handful of times a year.

IV. Observed Damage to Liberty Church and Appurtenant Structures

Dr. Engelstad described damage to the Church and Education Building that she attributes to the effect of blasting at the Oak Park Quarry. She also believes that vibration generated by blasting at the quarry is responsible for the movement of tombstones which have tilted or shifted on their bases. I have not been able to examine the Church, Education Building or cemetery; however, I have had the opportunity to examine photographs of the damage. Based on examination of these photographs, as well as descriptions of when specific damage occurred, I have been able to formulate preliminary opinions regarding the cause of some of the damage.

a. Spalling of the masonry near the ground level

Photographs of presented by Dr. Engelstad showed spalling of the masonry on the exterior of the church at and just above ground level. This type of damage is typical of masonry or concrete structures and is caused by repeated freezing and thawing of moisture that gets into small cracks in the masonry units or mortar and into pores in the mortar. With each cycle of freezing and thawing the damage becomes progressively worse. Damage of this type is typically the most severe near ground level where cyclic freezing and thawing of snow exacerbates the problem.

[8] ATS Consulting, (2008 - 2009), "Final EIS – Appendix J4, Vibration - Vibration Measurements and Predictions for Central Corridor LRT," Metropolitan Council

b. Vertical crack near window of church

I don't have sufficient information to have an opinion regarding the cause this crack.

c. Separation of joint in drywall in Education Building

Dr. Engelstad showed two photographs of a joint between a wall and ceiling in the Education Building that has opened up. The photographs were purportedly taken on September 2, 2015 and on February 20, 2016. The crack is significantly wider on February 20, 2016 than it was on September 2, 2015.

Joints in gypsum wallboard finishes attached to wood framing or joists typically open up as a result of cyclic shrinking and swelling of the wood frame. Wood is a dimensionally unstable material. When the relative humidity in the air is greater than the relative moisture content of the wood, the wood absorbs moisture from the air and swells. The opposite occur when the relative humidity in the air is less than the relative moisture content of the wood. The climate in this region tends toward relatively warm, humid summers and cold, dry winters. The low relative humidity in buildings during the winter months is exacerbated by heating if moisture is not injected into the heated, interior air by incorporation of a humidifier into the heating system.

Cracks and open joints similar to the one pictured by Dr. Engelstad are common in buildings in this part of the country. The cracks tend to close up during the summer months when the wood frame picks up moisture from the air and swells and open up during the winter when the wood frame dries and shrinks. Opening of the crack between September 2015 and February 2016 as shown on Dr. Engelstad's photographs is typical behavior for a crack or joint in gypsum wallboard attached to a wood frame or joists.

d. Vertical crack in concrete masonry (concrete masonry unit or CMU) wall of Education Building

I lack sufficient information to render an opinion regarding the origin or cause of this crack.

e. Shifting of tombstones

Dr. Engelstad showed photographs of tombstones that had shifted on their bases and attributed the movement to vibration generated by blasting at the Oak Park Quarry. However, the ability of vibration generated by blasting to cause movement of the tombstones can be ascertained by application of the basic principles of physics and solid body dynamics as follows.

For the purpose of analysis ground borne vibration is often approximated as simple sinusoidal motion. This assumption allows the relationship between particle velocity, acceleration and displacement to be defined by the basic, well-known relationships:

$D = \frac{V}{\pi F}$	$= \frac{GA}{2\pi^2 F^2}$	$= \frac{2V^2}{GA}$
$V = \pi FD$	$= \frac{GA}{2\pi F}$	$= \sqrt{\frac{GAD}{2}}$
$A = \frac{2\pi^2 F^2 D}{G}$	$= \frac{2\pi FV}{G}$	$= \frac{2V^2}{GD}$
$F = \sqrt{\frac{GA}{2\pi^2 D}}$	$= \frac{V}{\pi D}$	$= \frac{GA}{2\pi V}$

Equations for Sinusoidal Motion
Displacement (D), Velocity (V), Acceleration (A), and Frequency (F)

By applying the relationship between frequency and peak particle velocity to calculate the horizontal acceleration associated with each of the blasts monitored at Liberty Church, we find that the maximum horizontal acceleration was 0.16G which occurred on October 1, 2015 and is associated with the blast that had a PPV of 0.41 ips with an associated frequency of 24 Hz.

Then, by applying Newton's second and third laws of motion, we know that in order for the vibration to cause the tombstone to shift on its base the acceleration associated with the vibration must equal or exceed the static friction between the tombstone and its base. The sliding coefficient of friction for granite on granite is approximately 0.60 and the static coefficient of friction is between 0.75 and 0.80. Unless the horizontal acceleration of the ground vibration as a function of gravity is greater than the static coefficient of friction between the tombstone and its base, the tombstone will not move. It is readily seen that the maximum acceleration associated with any of the blasts monitored at Liberty Church is only approximately 21% of the acceleration necessary to cause a tombstone to begin to slide and only approximately 27% of the acceleration necessary to cause it to continue to slide once static friction is overcome.

V. Summary, Conclusions and Recommendations

a. Summary and Conclusions

Dr. Engelstad cites three references in support of her recommendation to reduce the limit on the maximum peak particle velocity at St. Paul's Liberty Lutheran Church to 0.12 ips for vibration generated by blasting at the Oak Park Quarry. Two of these references, specifically Wiffen (1971) and FTA (2006), deal only with vibration generated by highway and rail traffic or construction activity. The vibrations generated by these activities have long durations, occur frequently (e.g., many times a day) and typically persist over a period of months in the case of construction vibration and decades in the case of rail or highway or rail traffic. As such, by Dr. Engelstad's own admission, continuous, long-term vibration are typically more damaging than transient vibrations such as those caused by blasting. Therefore, the recommendations contained in the aforementioned references are not applicable to transient, short duration vibration generated by quarry blasting.

The one reference cited by Dr. Engelstad that does provide guidance on vibration caused by blasting (CALTRANS 2004) does not recommend limiting the peak particle velocity to 0.12 ips as claimed. Instead, CALTRANS reasonably recommends (CALTRANS, 2004, pp 60 and CALTRANS 2013, pp 79):

> *"Special care should be taken when blasting in close proximity to historically important structures. Such structures are usually of older, less competent construction, and lower vibration limits for them are often justified. These should be addressed on a case-by-case basis."*

None of the four, site specific, examples presented are relevant to vibration generated by quarry blasting. All of the examples deal with construction vibration associated with pile driving and/or drilled shafts (i.e., Stone masonry arch and de la Montaña Mausoleum at the Cypress Lawns Cemetery and the Shiloh Baptist Church in Columbus) or long-term, long-duration vibration caused by rail traffic (i.e., St. Louis King of France Catholic Church in St. Paul, Minnesota).

In summary, Dr. Engelstad has not presented a single authoritative reference or example that supports her proposal that the maximum peak particle velocity at St. Paul's Liberty Lutheran Church for vibration generated by quarry blasting should be limited to 0.12 ips.

Dr. Engelstad also presented a number of photographs illustrating what she claimed were damage to Liberty Church, the Education Building and the cemetery caused by blasting at the Oak Park Quarry. On the basis of the photographs alone, I have ample information to base my opinions that the spalling on the exterior of the church near ground level and the crack at the joint between the wall and the ceiling of the education building are caused by natural forces, not by vibration. Then, by the simple application of the basic laws of physics I showed that vibration generated by blasting at the Oak Park Quarry could not be responsible for shifting of the tombstones on their bases.

b. General Recommendations

My recommendations are in line with the recommendations made by CALTRANS and most of the other authorities on blasting operations and are as follows:

i. A condition survey should be completed on every building or significant structure within approximately ½ mile of the quarry. The condition survey should be overseen by a Structural Engineer licensed to practice in the State of Wisconsin and should document, both in field notes and photographs all cracks and other visible evidence of structural distress.

ii. Establish the limits for PPV consistent with the Wisconsin Administrative Code for all structures other than St. Paul's Liberty Lutheran Church and the round masonry barn.

iii. A seismograph should be located at a minimum of one dwelling or structure within ½ mile of the quarry, other than St. Paul's Liberty Lutheran Church, to monitor the vibration generated by each blast at Oak Park Quarry.

c. Recommendations Specific to St. Paul's Liberty Lutheran Church

i. Conduct existing condition survey - Condition surveys of St. Paul's Liberty Lutheran Church and Education Building should be completed by two Structural Engineers licensed to practice in the State of Wisconsin. Both of the Structural Engineers should have experience in evaluating the effects of construction and/or blasting vibration on buildings. One of the Structural Engineers should be retained by St. Paul's Liberty Lutheran Church and the other should be retained by the quarry operator. The Engineers should complete the on-site surveys concurrently and should exchange information regarding all cracks and other evidence of structural distress observed while they are on site. Each Engineer should maintain written field notes and photographs fully documenting the condition of the church and Education Building.

ii. Establish limiting vibration magnitude - Following completion of the condition surveys of St. Paul's Liberty Church the responsible Structural Engineers should exchange opinions pertaining to the ability of the church to withstand the transient vibration caused by blasting at the Oak Park Quarry and develop a consensus regarding the maximum peak particle velocity that the church can withstand without suffering even cosmetic damage.

iii. Monitor vibration at the church - The magnitude of vibration generated by all blasting conducted at the Oak Park Quarry should be monitored by a seismograph placed at the nearest corner of the church with respect to the quarry.

iv. Disseminate data - The data collected by monitoring each blast should be provided to a designated representative of the church as soon as practicable after each day on which blasting is conducted.

v. Appoint liaison - St. Paul's Liberty Lutheran Church should appoint one person as liaison with the quarry operator. This person should be responsible for all communication between the church and the quarry operator including relaying descriptions of all suspected damage or other concerns that members of the church might have to the quarry operator, as well as reviewing the blasting reports provided to the church by the quarry operator and disseminating this information to the membership.

I hereby certify that this report was prepared by me or under my direct supervision and that I am a duly licensed Professional Engineer under the laws of the State of Wisconsin.

Signed:  Date: 04/05/2016

Digitally signed:
Lawrence W. Gubbe, P.E.
Wisconsin License Number 13695