General Report — Session 4: Case Histories of Engineering Vibrations, Vibration Control for Underground and Surface Constructions with Specific Emphasis on the Urban Environment; Predictions, Monitoring and Solutions; Blasting for Tunnels in Soft Ground and Rock, Discontinuous Rocks and their Application to Water Resources Projects

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CASE HISTORIES OF ENGINEERING VIBRATIONS, VIBRATION CONTROL FOR UNDERGROUND AND SURFACE CONSTRUCTIONS WITH SPECIFIC EMPHASIS ON THE URBAN ENVIRONMENT; PREDICTIONS, MONITORING AND SOLUTIONS; BLASTING FOR TUNNELS IN SOFT GROUND AND ROCK, DISCONTINUOUS ROCKS AND THEIR APPLICATION TO WATER RESOURCES PROJECTS

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General Report – Session 4

INTRODUCTION

This General Report is presented in the four sections. The first section is an overview and introduction to the wide range of subject matters discussed, including but not limited to: Wave Propagation Theory, Measured Vibrations In-Situ, Machine and Facility Foundations, Computer Modeling and Finite Element, Pile and Pier Cap Foundations, Blasting Vibrations, and Soil Improvement. The second section includes a brief summary of each paper. The third section tabulates the author's names, paper titles, field of application, summary of content, approach and originating country, and the final section includes some closing remarks and topics for discussion.

SUMMARY OF RELATED TOPICS

Introduction

The topics discussed in this session's papers include at least one of the following, for which a brief introduction follows:

- Wave Propagation Theory
- Measured Vibrations In-Situ
- Machine and Facility Foundations
- Computer Modeling, Numerical Analysis, Finite Element and the Advancement of Vibration Transmission Theory
- Deep Foundations: Rammed Aggregate Piers, Scrap tire Vibration Isolation Method for Steel Pipe and Prestressed High-Strength Concrete (PHC) Piles and Lateral Pile Cap Capacity
- Drill and Blasting Vibrations
- Soil Improvement
- Standard Penetration Test Hammer Energy
- Water-Borne Pressure Waves

The papers range from factual summary accounts of case histories which were practical in nature to those which are research based and more on the theoretical side. Many included measured comparisons of before and after some physical change that occurred that in turn affected the vibration transmission or the dynamic soil-structure interaction. Vibrations measured and/or computed or estimated were from "uncontrolled" active mechanical or civil operations or construction activity and also from "controlled" sources which were generated using known masses and/or calibrated drop weights. Many papers derived, proposed or implemented solutions to "after the fact" problems that arose following:

- poor citing or planning,
- lacking or incomplete geotechnical investigations,
- inadequate foundation designs with lack of consideration to unbalanced loads, dynamic response, first and second natural frequencies, or cumulative effects of multiple vibration input sources,
- faulty construction combined with a lack of construction oversight to provide quality assurance, or, improper maintenance

Wave Propagation Theory

Most of the papers in this session deal in one way or another with the transmission of vibrations from an energy source to a receptor. Energy sources varied from operating machines and facilities to vehicular cars and trucks, pile drivers, rammed aggregate pier installations, small hammers used as a repeatable test input energies, large drop weights used in static-dynamic compaction, Standard Penetration Test (SPT) hammers and drill and blast detonations. Receptors also varied, but were generally adjacent property owners or facilities ranging from residential houses to underground tunnels to buried pipelines to large industrial or commercial complexes. Many papers discussed or included theoretical formulae for computing or estimating vibration magnitudes at varying distances from the source. Most referenced previous studies on similar subject matter and some proposed new methods or new approaches.

Measured Vibrations In-Situ

As most of the case histories summarized by the authors of this session dealt with vibrations, most measured vibrations in-situ using various makes and models of seismographs, accelerometers and data collection devices. Many were triaxial sensors and most mobilized numerous sensors along linear arrays extending away from the source or multiple sensors located on or around the perimeter of the foundation or object in question. Generally, not a lot of detail was provided as to how the sensors were installed, meaning were they sandbagged, buried in soil or bolted to structures, any of which may be appropriate as a function of the surrounding geologic formation and the magnitude of the vibration anticipated at the measuring point. Many of the papers provided illustrations of raw or processed data and plots of vibration attenuation versus distance or scaled distance for varying conditions.

Machine and Facility Foundations

The most frequent case histories cited in the session (about six papers) were problems caused by machines or facilities operating on foundations through which annoying and damaging vibrations were transmitted to surrounding structures. In some cases the vibrations were strong enough to damage or prevent the existing system from functioning properly or to cease functioning entirely, while in other cases the problem was limited to complaints issued by neighboring property users. Several of the papers contained initial measurements of existing conditions, the progressed into computer modeling analysis and prediction of vibrations from various proposed options before implementing a modification and measuring the reduction in vibrations to quantify the benefit of the solution.

Multiple papers discussed the concept or dilemma that while better isolating a machine from its foundation (say removing springs) results in less vibration transmission to the surrounding ground, it increases the dynamic stress on the machine itself as it is forced to absorb the energy no longer transmitted to the ground, which is generally very effective at providing damping. The alternative of better coupling the machine and its foundation can result in greater vibration transmission to the surrounding ground, yet less stress on the machine. This balance referred to as a reverse vibration absorber approach and the numerous variables involved make each site-specific project an interesting case history from which others can learn and appreciate the complexity and importance of good complete geotechnical investigations, foundation design.

Computer Modeling, Numerical Analysis, Finite Element and Soil Structure Interaction and the advancement of Wave Transmission Theoretical Analysis Procedures

Two and three-dimensional Plaxis, SASSI (A System for Analysis of Soil Structure Interaction) and DASYLab appeared to be the most cited computer aids or models utilized to compute, estimate, process data or verify vibration problems or analysis performed. Many authors described the need for calibrating the model using; (1) quality input soil parameters measured through subsurface investigations designed specifically with considerations for static and dynamic parameters, and (2) in-situ vibration measurements at various stages of construction. Some utilized upper and lower bound soil parameters, while others established unique values for the model. Different constitutive models were used to define the soils and structures.

Input parameters included density, soil friction angle, Poisson's ratio and damping ratios among others. Several authors delved into vibration attenuation theory and drew from existing studies or proposed new formulas for prediction or improving vibration estimates at distance from a source. One closely examined formulas used to interpret pore pressure dissipation and soil stress-strain and shear modulus behavior (using the constitutive law and the hypo-elastic model). Governing equations are presented. Another reviewed complex Fourier motion equations considering frequency and angular frequency, vector displacements, natural frequencies or eigenvectors, mass and impedance of the soil-foundation system and external forces. Papers included topics such as vehicular bridges, underground tunnel openings, buried pipelines and machine or plant/facility foundations.

Deep Foundations: Rammed Aggregate Piers, Scrap tire Vibration Isolation Method for Steel Pipe and Prestressed High-Strength Concrete (PHC) Piles and Lateral Pile Cap Capacity

Three papers addressed deep foundations in very different ways. One measured noise and vibrations at varying distances from rammed aggregate pier installations while a second utilized scrap tires encompassing pipe and prestressed high-strength concrete piles to form an isolation or reduction barrier through which vibrations would be reduced. A third paper addressed the geotechnical design issue of lateral capacity of pile caps, comparing United States practice with that of the Chinese Code.

Drill and Blasting Vibrations

Two papers addressed vibration transmission from drill and blasting projects. These two projects were both on different sides of the globe and also different sides of the drill and blast spectrum. One summarized three urban blasting projects where relatively small charges were detonated in close proximity to urban infrastructure while the other described huge strip mining detonations intended to clear overburden and expose coal resources layered deep underground. Both papers addressed and proposed improved means of evaluating and interpreting the data and both recommended additional research and publication of such case histories to further develop the field. The latter paper included data that challenged or was at least contrary to the common observation that the maximum charge per delay controls the peak measured vibration.

Soil Improvement

At least two papers included ground improvement techniques, one using grout injection to improve foundation support and to minimize displacements of the machine and its foundation, and a second utilizing a static-dynamic method (dynamic compaction) technique and comparing several varying shaped and mass tampers to consolidate soft compressible ground. Both papers measured in-situ vibrations.

Standard Penetration Test Hammer Energy

This subject paper addresses the energy transmitted from direct impact of the driving force, a weighted hammer, free falling a particular distance in efforts to apply a "standard" energy to a driven sampler. Measurements were taken to record and database the "efficiency" of this energy transfer. A large database of measurements for varying systems is included.

Water-Borne Pressure Waves

One paper dealt with pressure and sound waves originating from construction activities which propagate from land or over water through the water column and can be detrimental to aquatic organisms and steel and concrete structures.

INDIVIDUAL PAPER REVIEWS

There were a total of seventeen papers submitted to this session from a total of eight countries as listed in Table 1 located at the end of this section. Contributing countries included Japan, Switzerland, United States, China, Iran, Turkey, Romania and India.

Each paper is briefly summarized below as was interpreted by the writers of this General Report. Readers of this General Report are encouraged to read each paper in entirety such as to draw their own inferences from the work of each author and such as not to base their opinions on the brief summaries provided in this General Report. Readers are also encouraged to review the reference lists provided in any paper in which they find or have an interest as many additional quality publications regarding the referenced subject are available. It is our ethical duty as Scholars, Professionals Engineers and/or Contractors to share and publish our Case Histories and to openly discuss or debate as it may be, our experiences (both successes and failures) to advance our understanding of these subjects for the future benefit of the field.

Paper #4.01 by Hayakawa, K., Nakaya I., Nisimura, T. titled, "The Spread Phenomenon of a Low Frequency Ground Vibration to Originate in the Highway Bridge and its Simulation Analysis" describes a case history in which vibrations from vehicular traffic on an elevated bridge structure transmitted disturbing vibrations to three private two to three story houses located approximately 80 meters (260 ft) from the bridge and one larger and closer presumably commercial or industrial type building. The authors introduced and described the configuration of the bridge in which passing vehicles created vibrations each time their axles passed over the bridge deck joints located above the bridge piers. Using a combination of velocity transducers and accelerometers, they instrumented:

- the bridge at the base and top of the piers (beneath the bridge deck joints),
- the bridge at mid-spans along the deck, and
- three nearby private houses and one larger building

The authors provide waveform time histories of accelerations of the bridge deck, pier foundations as well as Fourier spectra of several of the nearby structures. The authors indicate that the vibrations recorded in the houses amplified due to the congruence between the natural frequency of the two and three-story private houses and that of the input or source vibrations from the bridge transmitted into the surrounding ground (say 2 to 5 Hz). Recorded vibrations in one house were as much as 10 times that recorded in the ground outside the house due to resonance resulting in amplification.

The authors performed a computational simulation of the bridge using a two dimensional finite element model. They determined input parameters (S-wave and P-wave values) using available geotechnical information and adjusted spring values to obtain the characteristic frequency of vibrations of 3.0 to 3.6 Hz for different components of the bridge as was recorded during the instrumentation phase. The finite element model predicted vertical vibrations reasonably well, while it underestimated horizontal vibrations in the ground surrounding the private houses.

The authors present an interesting case history in which the transmission of vibrations from the bridge structure result in amplified vibrations at nearby structures. The recorded measurements from instruments attached to the bridge, ground and houses provide documented evidence of the phenomenon where vibration amplification occurs when source vibrations fall in the range of natural frequencies of adjacent structures.

The authors show that this phenomenon can be confirmed using two-dimensional finite element models. The writer infers from the authors that while they were able to refine the model to predict the vertical vibration transmission from bridge to structure reasonably well, the model continued to under predict the horizontal vibration transmission between these same points. This example provides evidence of the potential and also difficulty in modeling complex three-dimensional geotechnical soil-structure interaction problems involving vibrations.

Paper #4.02 by Nakaya I., Hayakawa, K. and Takahiko K. titled, "In-Site and Model Experiments About Ground Vibration Isolation Method by Using Scrap Tire" presents full scale field and model tests of scrap compressed tires installed as isolation components around the circumference of steel pipe and prestressed high strength concrete piles (PHC). Steel pipe piles of 36 cm (14 in) outside diameter and PHC piles of 30 cm (12 in) outside diameter were encapsulated with rubber scrap tires forming 70 cm (28 in) outside diameter composite piles. All piles were filled with sand. Similarly constructed alignments of steel pipe and PHC piles were then installed tangent to each other to provide two continuous L-shaped barriers measuring 9.8 m (32 ft) along the long edge and 3.5 m (11.5 ft) along the short edge.

Vertical excitation accelerations from a drop hammer as an excitation source and resulting vertical and horizontal ground vibrations were measured at multiple locations using five portable vibration meters (manufactured by Rion Inc.) and a data recorder. Measurement locations included in front of, on top of, and behind each wall alignment to obtain degradation of vibration energy across the in-situ barrier alignment. The tire encapsulated steel pipe and PHC isolation barrier alignments provided a reduction (attenuation) of vibrations from a point source applied at the ground surface equivalent to 8m (26 ft) and 9m (29.5 ft) of natural ground respectively. In other words, the reduction in vibrations across the 70 cm (28 in) thick barrier wall was equivalent to the vibration attenuation that would occur naturally across about 8.5 m (28 ft) of natural ground at this site.

The authors provide results of previous studies comparing these data to an open isolation trench and one using the original uncompressed tire model with these compressed tire composites. They discuss vibration and wave motion theory including acceleration ratios computed from the wave motion impedance ratio, the thickness of the medium, the vibration frequency and the wavelength. The measured values fell between calculated upper and lower bound values using varied cross-sectional parameters for the tire material. A better agreement between measured and calculated values of vibration degradation across the barrier resulted after incorporating frequency and damping ratios into their calculations.

Model experiments suggested that:

- filling the composite with sand, as opposed to leaving it open or filled with air, has the effect of reflecting acceleration energy back towards the source, while the measured accelerations behind the wall remained similar and,
- the compressed tire composite was more effective than a previously attempted "original" tire composite in isolating accelerations across the barrier.

The authors present a use and concept for recycling rubber tires as a potential means for addressing a growing concern for minimizing waste that otherwise ends up in landfills. They present a vibration minimizing barrier wall formed of composite piles formed using recycled rubber tires encapsulating standard pipe or prestressed high strength concrete piles. They provide measured data from full scale field and model tests and present wave propagation theory to support the degradation of ground accelerations from a surface waves across the in-situ barrier formed by these tangent piles.

The writer's did not describe the process through which the piles are constructed or installed. There would appear to be logistical issues and high labor costs associated with fabricating, handling and installing these piles in practice. These or similar isolation barriers may provide an alternative to continuous barriers formed by slurry trench excavation construction and may become a viable or preferred option as growing waste concerns need be addressed on a local or regional scale.

Paper #4.04 by Studer J.A., Panduri R., Höltschi, H.P., titled "Synchrotron Facilities: Meeting Stringent Deformation and Vibration Criteria" presents two case histories on two very different geologic sites where vibration amplitudes are limited to 0.4 to 4 micrometers between 0.05 to 100 Hz, absolute deformations are limited to 1 micrometer under static and dynamic foundation loading, and differential displacements are limited to 0.25 mm per 10 m per year (0.01 inches per 32 ft per year). One site, in Spain, consisted of layered sandstones and marls with swelling clays and fluctuating groundwater levels, while the opposing site in Switzerland were favorable, consisting of dense glacial sandy gravel with sand and silt layers over bedrock with a near constant and deep groundwater table.

The authors recognize that the foundation systems which best minimize vibrations are not consistent with those that meet the stringent settlement criteria, and vice versa. Further, the vibration criterion was defined by the amplitude of the vibration displacement and as such was controlled by long period vibrations.

The authors discuss two vibration sources, those from on the test platform (from the system itself) and those from off the test platform (ambient or background vibrations). They highlight that while isolation of the test platform from the ground using springs is preferable to minimize impact from ambient vibrations, it contrasts with the preferred solution to minimize vibrations from the machinery mounted on the platform itself. This would be achieved by opposing means, i.e., connecting the platform firmly with the underlying ground, thereby obtaining the highest system damping. Note that due to the strict deformation requirements, these systems apparently employ no material damping in the test platform itself.

One test site contained swelling clays to 60 meter (200 ft) depth, requiring that the foundation design consider:

- a stiff mat foundation on elastic supports, i.e., supported on springs with a gravel substrata to serve as an impendence drop without significantly reducing the damping,
- deep piles founded below the swelling soils, or
- shallow micropiles as settlement reducers to minimize differential settlements by "homogenizing" the subsurface.

Factoring in cost, the stiff mat foundation was selected. The authors report that vibration reduction across the mat to gravel interface (impedance drop) is very high for frequencies above 20 Hz and "considerably" reduced down to the 1 Hz range below which there are few or no practical countermeasures. Isolation trenches were considered as a possible means of further reducing ambient off-site vibrations by as much as 60%, but they were not used, highlighting that if not properly configured, they can reflect vibrations and exacerbate the situation. It was considered more cost effective to recommend maintaining nearby roads to provide smooth surfaces and eliminate pot-holes which become source vibrations when encountered by large trucks. Countermeasures such as these are often overlooked as viable actions to reduce vibrations.

Inside the test facility, vibration producing equipment was carefully located such as to minimize vibrations to the most sensitive areas. Components of the damping systems were carefully evaluated and selected such as not to coincide with the natural frequencies of the subsurface, structure or mechanical equipment. Careful construction techniques were employed, such as:

- minimizing subgrade disturbance using toothless buckets for the final 50 cm (20 inches),
- over excavating and replacing silt and loose sand layers or pockets with lean concrete, and
- hydraulic considerations, i.e., diverting stormwater runoff during construction, pouring lean concrete following excavation to protect exposed subgrades, and a permanent sub-slab drainage system,
- segmenting the concrete slab pours into smaller sections with roughened joints and continuous reinforcing elements.

The paper presented a challenging pair of case histories where stricter than normal vibration and displacement criteria were addressed from the early stages of design.

Paper #4.05 by Fiegel G. L., Farrell T. M., titled "Measurement of Vibration and Noise during the Installation of Rammed Aggregate Piers" presents construction noise and vibration monitoring data collected between 1.5 and 10 meters from the hammer during 45 pier installations. Data were collected using a triaxial geophone manufactured by Instantel anchored to the ground using a sandbag and a sound level meter manufactured by Quest Technologies included 160 ground vibration measurements and 260 noise measurements. Peak ground velocities ranged between 0.5 and 15 mm/sec (0.02 and 0.6 in/sec) and measured noise levels ranged from 82 to 111 dBA at horizontal distances between 1.5 and 10.5 meters (5 to 35 ft) from the hammer.

The rammed aggregate piers (RAPs) were constructed by auger drilling 762 to 838 mm (30 to 33 inch) shafts to depths of 2 to 9 meters (6 to 30 ft) and from the bottom up, ramming 50 mm (2 in) aggregate to form an enlarged stable base followed by 19 to 38 mm (3/4 to 1.5 in) stone rammed in 304 mm (12 in) lifts. The equipment included a 200 kN (45,000 lb) hydraulic excavator with a 15.6 kN (3,500 lb) hydraulic hammer operated at 300 to 500 blows per minute delivering an equivalent hammer energy between 1,300 and 2,600 kilo-Joules (1 and 2 million ft-lbs). Where temporary casings are not necessary to maintain an open hole, typical installation rates for similar depths and soil conditions vary from 35 to 60 RAPs per day. Load tests proved the RAPs exhibited a measured stiffness modulus greater than 135 MN/m^3 (498 pci) and withstood a top stress of 7,660 kPa (8 tsf) with less than 50 mm (2 in) of deflection.

The site was located in San Luis Obispo, California adjacent to a seasonal creek where soils consisted of alluvial medium stiff to stiff clays and silts with varying amounts of sands and gravel and Standard Penetration Test N-Values ranging from 5 to 25 blows per 30 cm (blows per foot) and a groundwater level which raised from 5 to 3.6 m (17 to 12 ft) below grade from the time of the geotechnical investigation to the time of RAP installation.

Once the data were recorded, the authors presented the following interpretation:

- the horizontal versus focal distance between the energy source and the sensor, where less scatter in the data are observed when one uses the more accurate distance computed as the true travel path of the vibration from the source to the instrument as opposed merely the plan horizontal direction,

- statistical results for zero-crossing frequencies, arithmetic means (36 to 38 Hz) and standard deviations (10.8 Hz for longitudinal and vertical, and 17.5 Hz in the vertical direction). The authors report no distinct trends in the averages of zero crossing frequencies over horizontal distances through which measurements were taken.
- With the sound level meter positioned at a constant height above grade, recorded sound levels were loudest with the hammer at its highest point. Further, they near linearly dissipated with the height of the hammer above the ground surface. Comparing data collected between 1.5 m (5 ft) and 10.5 m (35 ft) from the pier installations, the sound levels near linearly decreased from a range of 97 to 111 dBA when the hammer was about 2.5 m (8 ft) above grade, to between 84 to 100 dBA with the hammer driven to 1 ft below grade. They compare these data to that of typical construction equipment such as air compressors at 87 dBA, jack hammers at 94 dBA, impact rock drills at 104 dBA, and pile drivers at 107 dBA.
- The authors compared the recorded vibration attenuation data with published data suggesting RAP installation causes vibrations higher than those from small bulldozers, similar to jack hammers and large bulldozers and well below vibratory an diesel pile hammers. They compare the frequency based particle velocity relationship to the U.S. Surface Mining Safe Blasting Criteria envelope.
- Referencing the equation $PV = kD^{-m}$, the authors compute confinement factors, k, and attenuation coefficients, m, for RAP and compare them to those in the literature.

Paper #4.06 by Biringen, E., Davie, J. presents 220 additional field measurements of hammer energy data from 32 different automatic hammers on sites ranging from soft clays to silty sands to partially weathered rock at depths ranging up to 122 m (400 ft). They compare automatic hammers to safety hammers, and review that uncorrected variations of more efficient hammers will result in underestimating soil density and potentially an overly conservative design.

The authors review the theoretical and typical energy transfers and the widely accepted standard of 60% of theoretical leading to the N_{60} relationship = N_{field} (ETR/E_{60}). They report an overall average energy correction factor of 1.36 with a range of 1.25 to 1.46.

Their field measurement system consisted of a PAK model Pile Dynamic Analyzer (PDA) with calibrated accelerometers and strain gages mounted on two-foot long drill rod sections connected at the top of the drill string directly below the hammer. Strain and acceleration data were converted to force and velocity using the PDA, and then to maximum transferred energy using the Case method.

The authors compare these data to typical data in North America, the United Kingdom and China, and to published data from the Florida and Utah Departments of Transportation (DOT). The authors tabulated all of the data including case history number, rig model, location, depth of sampling, soil type (by the Unified Soil Classification System group name), rod type, recorded SPT N-value, frequency of hammer blows and the computed Energy Transfer Ratio in percent. They provide average ETR for each rig model in the study and a comparison of initial versus retests on the same rigs to evaluate reliability of individual tests. The recent data are in reasonable agreement and further support published data.

Paper # 4.08 by Li, Z. M., Lin, J.H., titled "A Case – Vibration Influences and its Evaluation in Muck Ground Improvement with the Static-Dynamic Method" presents a comparison of four tamper geometries used as drop weights in dynamic compaction projects. Vibration acceleration tests and resulting settlements are measured. The 186,000 m^2 (46 acres) soft ground site contained a 12 m (39 ft) thick organic clay layer with an average water content of 75% (maximum 114%) and an average void ratio of 2.09 (maximum 2.99). The authors define a Static-Dynamic Drainage Consolidation Method (SDDCM) combining a static force resulting from a 1.5 m (5ft) working platform of sand fill placed two to three months prior to dynamic compaction, installation of wick drains to a depth of 15 m (50 ft) at a grid spacing of 1.4 m (4.6 ft) dynamic load from the dropping weight at a point spacing of 5.5 m (18 ft), residual soil self weight loading, and rapid drainage presumably squeezing water into the permeable surface drainage layer.

The authors measured accelerations of the four types of tampers or drop weights and the resulting ground vibrations with distance from the impact location with piezoelectric accelerometers. The instruments had a frequency response of 0.2 to 3,000 Hz, a range of 0 to 150 g, and a sample rate of 100 kHz/8 Channels or a single channel maximum of 20 kHz.

The four tampers ranged from 13 to 16 tons, from 2 to 2.5 m (6.5 to 8.2 ft) in diameter, and from 1 to 1.2 m (3 to 4 ft) in height. Each drop weight contained four holes of varying diameters and each weight was dropped from a 6.5 to 7.5 m (21 to 25 ft) height, resulting in temping energies between 975 and 1125 kN-m (830 kip-ft). The shock absorbed and assembled tamper (SAAT) designed by one of the authors best transmitted the drop energy into the ground by emitting the lowest horizontal and vertical accelerations, meeting a referenced Code criteria for a magnitude 7 earthquake at a distance of 20 m (66 ft) from the point of impact as <0.1g horizontal and <0.2g vertical. Further, the tamper appeared to produce the same amount of settlement in fewer drops supporting that greater energy transfer occurred vertically into the ground below rather than laterally at the surface.

The SAAT tamper draws from a concept used in blasting, where as millisecond delays between charges in a blast result in a decrease in vibration at a particular distance from the blast. In this case, millisecond delays between multiple impacts occur due to the geometry of the tamper and its small projected cylinders on the bottom side. The holes in the tamper facilitated air flow by reducing air resistance, thus creating a larger and more balanced or level impact such as not to lose energy laterally in the event of tilting between the bottom of the tamper and the ground surface at the point of impact.

During impact, measured vertical accelerations were 2.67 times horizontal accelerations. The authors report a significant decrease of measured vertical acceleration in the first 10 m (33 ft) laterally from the point of impact, and slower decay between 10 m and 30 m (33 and 100 ft). Likewise, they report a larger horizontal decrease in the first 5 m (16 ft) from the point of impact and a slower degradation between 5 and 30 m (16 and 100 ft).

The paper concludes that this form of compaction can be made more efficient and cost effective by using well designed tamper geometries formed by closely studying the phases of the tamper impact with the ground surface, which the authors have divided into three stages. They propose that vibrations can be reduced by 20 to 60% by selecting the appropriate tamper, and that where and in conjunction with isolation trenches, it may be used successfully in close proximity to adjacent buildings.

Paper #4.09 by Tajirian, F., Tabatabaie, M., Asiri, F., Seryi, A. titled "Calibration of Computer Program SASSI for Vibration Transmissibility Analysis in Underground Structures using Field Measured Data" presents a case history of using a three-dimensional finite element program (SASSI) to successfully model a section of the Los Angles twin underground tunnels as evidenced by recorded field measurements. The authors propose that it can be used to:

- model underground openings,
- estimate and thereby control vibrations,
- optimize design of equipment supports to minimize transmission of vibrations,
- calculate the impact of existing background, construction and quarrying vibrations on the operation of vibration sensitive structures

The authors established density, Poisson's ratio and upper and lower bound shear wave velocities for five subsurface layers from available subsurface information. The site contained about six meters (20 ft) of soil over Miocene sandstone and shale of the Topanga formation. The geometry of the twin tube tunnels and the existing two planes of symmetry facilitated a simplification in that only one-quarter of a single tunnel was included in the finite element model.

The authors carried out five in-situ vibration tests to obtain data for comparison to estimates from the model. They measured the acceleration of the input vibration source [100 kg (220 lb) drop weight] using a 500-g piezoelectric accelerometer and they used an array of sensors to record the dynamic response at varying distances from the source. The measured acceleration data of the drop weight was used as input in the SASSI finite element computer model analysis. They obtained time history measurements of transmitted vibrations from ground surface to points at grade and to a 28 meter (90 ft) deep tunnel, transmission of vibrations along the length of a single tunnel, and transmission of vibrations from one tunnel to the other tunnel.

The lower bound soil parameters provided better agreement with the analytical results. The calculated and measured mobilities, peak particle velocities and peak displacements were in good agreement, suggesting the three-dimensional SASSI computer model can be used to predict vibration attenuation. This approach can be used to predict vibrations for buildings and underground tunnels and pipes and to evaluate different options of isolating these structures from vibration sources.

Paper #4.12 by Zheng, W. titled "Large Pile Group Design Optimization with Lateral Resistance of Pile Cap" presents the issue of lateral passive resistance and its influence on optimizing the pile cap shape. The author compares a method used in the United States [FEMA 356 (2000)] with that of the Chinese Design Code [JGJ 94-94(1995)].

The passive lateral resistance of pile caps is often ignored in practice because:

- the lateral displacement may not be enough to mobilize the full passive resistance,
- the potential for this soil to settle away or be excavated from the pile cap.

The author presents that in some cases however, especially for industrial or large high rise structures, the pile caps can be massive and deeply buried and as such the pile cap may offer significant lateral resistance. The author makes references to several previous studies where a significant portion of the lateral load was provided by the lateral resistance of the pile caps.

Incorporating the lateral resistance offered by the passive soil on the resisting side of the pile cap resulted in an optimization in geometry to a large strip-shaped pile cap.

The FEMA approach includes a pile cap hyperbolic function p-y curve defining the relationship between lateral displacement normalized as a function of the pile cap thickness to passive pressure mobilization, in percent. The JGJ approach includes two components, the lateral earth resistance in front of the pile cap and the frictional resistance along the base of the pile cap. The lateral deflection of the pile caps is limited as a function of the importance of the structure. The passive resisting soil is therefore modeled using elastic Winkler springs with linearly increasing stiffness with depth for small deflections.

The author summarizes the p-multiplier approach to pile group analysis in which individual piles are assigned factors based on their location in the pile group and the pile spacing. Based on the geometry, some piles are shadowed and do not work as efficiently as others within the pile group. While practice in the United States is to consider the pile spacing and number of pile rows parallel to load application, the JGJ approach also includes consideration of the pile spacing perpendicular to the application of load.

The author describes a case history in Nanjing City, China, where 32 meter (105 ft) prestressed high strength concrete piles were installed through a subsurface profile of a thin backfill layer over about 15 meters (50 ft) of soft clay over 11 meters (36 ft) of silty sand over very dense sand at a depth of 30 meters (98 ft). Vertical capacities were estimated at 150 kN (175 tons) compression and 775 kN (87 tons) tension. Lateral capacities were calculated using the computer program LPILE using both free and fixed head conditions. Analysis estimated allowable lateral capacities of individual piles between 122 to 207 kN (13 to 23 tons) for free and fixed head conditions respectively, at 10 mm (0.4 inches) deflection.

The consideration of optimizing the pile spacing on the shorter side of the pile group resulted in a 15% reduction in the number of piles from 140 in the original design to 114 in the final design.

Paper #4.16 by Halabian, A. M., Hashemolhosseini, S. H., Rezaei, M. titled "Nonlinear Seismic Analysis of Buried Pipelines during Liquefaction" presents a study to incorporate soil liquefaction potential into computational analysis (finite element modeling) of buried pipelines during an earthquake event. Analyses of time histories provide soil-pipe interaction phenomena to evaluate the effect of soil cyclic nonlinear behavior introduced by soil liquefaction. The constitutive model for saturated liquefiable sandy soil is assumed to show hysteretic characteristics based on undrained conditions, leading to the use of a hypo-elastic constitutive model to evaluate the shear modulus as a function of effective shear stress or shear strain.

The authors consider transient and permanent ground deformations including settlement and lateral spreading, and address changes in effective stress, soil volume, simple shear deformations, pore pressure and stiffness. They incorporate a hypo-elastic model for the soil and use beam elements and bi-linear springs for the pipe and soil outside the potential liquefaction zone while using shell and solid elements respectively for the pipe and soil in the zone where liquefaction is likely to occur.

The paper presents an effective stress method and nonlinear constitutive relation model to study the changes in effective stress (development and dissipation of pore water pressure) during seismic excitation. The authors review and include an algorithm defining the hysteretic loops for liquefiable sands. As shown by example, a three-dimensional finite element model of a pipeline in liquefiable sands, the methodology can predict the rise and dissipation of pore pressure coupled with the corresponding loss of soil strength which occurs during liquefaction.

Paper #4.17 by Hempen, G. L. titled "Destructive Water-Bourne Pressure Waves" presents that energy sources near or within a body of water can produce pressure waves of sufficient amplitude to negatively impact water-side structures and fauna. Blasting, pile driving and seismic exploration in or near the water are example construction activities that are known, or have proven, to cause cavitations and spall concrete or deform metal sheets and/or damage the hearing or cause the death of aquatic organisms. Methodologies to reduce the severity of the negative impacts of pressure waves generated by these and other construction related activities are presented which will not adversely affect the efficiency of the energetic source.

The author has divided the paper into sections on energetic sources, namely blasting, pile driving, seismic exploration and military testing.

Regarding blasting, the author describes waterborne versus terrestrial effects of key blast elements, including the layout of the blasts in the water column, the blast initiation sequence, explosive type, charge weight, hole pattern, charge per delay, delay type and sequence, confinement by stemming, wave transmission types and distance to the point of interest.

In pile driving, pressure waves are developed in the water column as the pile develops side-friction or end-bearing capacity and the severity of the pressure waves are a factor of hammer energies, lead systems (fixed or free), pile caps, end versus friction bearing, pile length and types of piles as well as the water depth and site geology beneath the water column. Discussions are presented on each factor.

The author notes that fluids only support pressure or compression or sonic waves, but adds that for instance, that cylindrical wavefronts generated as shear waves from piles being driven into soil translate into compression waves at the soil-water interface. Another example provided is that noise is transmitted as planar pressure waves into the water from such sources as the entire wetted surface of a barge upon which pile driving operations occur.

Seismic exploration for minerals typically includes a repeating mechanical pulse towed behind a vessel, releasing energy downward into the water column as a point source attenuating along a narrow, focused cone of influence.

Using site geology and known water properties, approximate compression-wave velocity models can be developed. The sonic velocity of water varies with the depth, temperature and salinity and may be predicted by formula. The author notes that while water is generally considered incompressible, it is compressible near the detonation front of explosives.

As a pressure wave approaches the air-water surface, the waves change from compression to tension resulting in cavitation as the wave's compression amplitude exceeds the atmospheric pressure on the water surface.

While structures are usually not affected by energetic sources more than 10 to 15 meters (33 to 50 ft) from the source, aquatic marine organisms may be affected hundreds of meters from the same source. Stringent regulations exist with respect to endangering the life of particular species in the aquatic environment, and these issues can result in delays or shut downs.

The author describes potential mitigation sources for minimizing negative impacts from waterborne energetic sources. There are physical barriers such as sheet pile walls which can reflect, refract, diffract and attenuate pressure waves and there are air curtains, air screens or bubble curtains which can be very effective at reducing energy through reflection and attenuation.

Continuous work operation allows organisms to sense the activity, then to move away and stay away from the source during the work. Seasonal restrictions (due to fauna breeding times) may be appropriate or required. In pile driving operations, containment barrier walls and a containment pipe pile are the only appropriate mitigation measures. They are generally vibrated or jetted into position, and must be deep enough to be effective, the greater of twice the water depth, embedded into a dense or stiff underlying soil layer, or one quarter of the total pile depth.

In conclusion, the author reviews that sufficient advance study is necessary to minimize the potential for damage to structures and aquatic organisms from construction activity in or near the water. Studies will require site-specific subsurface exploration, the cost-benefit of mitigation measures, the inclusion of mitigation measures, if required, in project specifications, and compliance monitoring.

Paper #4.18 by Arsoy, S. titled "Mitigation of Adverse Vibrations in nearby Structures arising from a Large Forge Hammer" presents a case history of rehabilitation of support for an active machine accomplished by reducing the number of springs between the foundation and the machine, thereby reducing the foundation amplitude and increasing the machine's amplitude.

Machine operations had commenced in 2007 and shortly thereafter complaints were received from neighboring facilities as far as 300 meters (985 ft) away. The objective of the study was to develop a quick solution to the problem at optimal cost such as to minimize impact to the active machine operation. It was concluded that the 22 m^2 (240 ft^2) foundation was designed primarily based on engineering judgment and as such, with inadequate site-specific subsurface information or engineering analysis. The machine was originally mounted on 96 springs plus a polyurethane block at each of four corners, resulting in a total calculated spring constant of 280,000 kN/m (1,600 kips/inch).

In the solutions phase of the project, the machine was modeled as two single degree of freedom systems with two masses and two soil springs without any appreciable damping. The soil spring values were estimated from an average SPT N-value of 17 and an average shear wave velocity of 150 m/s (492 ft/s), resulting in an averaged computed vertical soil spring constant of 900,000 kN/m (5,000 kips/inch). The author computed the corresponding natural frequencies and displacement amplitudes as 130 Hz and 1.1 mm (0.04") for the foundation and 44 Hz and 4.1 mm (0.16") for the machine.

The author reviews options for mitigating machine vibrations, as follows:

- Reducing the source vibrations,
- Active vibration barriers to limit travel distances,
- Passive vibration barriers at other structures

In this case, the best long term solutions were considered as improving the soil or improving the foundations by installing piles in conjunction with a vibration barrier. Due to time and monetary constraints, reducing the machine vibrations was the only option implemented. The author reviews the reverse vibration absorber approach in which the foundation is isolated from the machine and the machine acts as a vibration isolator block, i.e. that reducing the machine's springs would decrease foundation amplitudes and minimize source vibration transfer to adjacent facilities. This also increases the machine's vibrations however, potentially leading to long term maintenance costs of the machine itself. Alternatively, reducing machine vibrations by adding springs dampens energy by transferring it to the underlying soil could result in higher and unacceptable vibrations at adjacent facilities without ground improvements, additional pile support, vibration barriers, or passive vibration control within the adjacent facilities.

After computing the effect of several alternatives and considering the time and cost-benefits of each, a joint decision between the Engineer and Owner was made to reduce the number of springs between the machine and the foundation from 96 to 40.

Measurements of maximum vertical and horizontal peak particle velocity and acceleration were recorded and tabulated with traixial accelerometers at six locations varying from 40 to 200 m (130 to 260 ft) from the machine foundation. The modification to the springs reduced the foundation amplitude by 50%, resulting in a corresponding increase in machine amplitude of 85%. The modifications were completed in six hours.

Paper #4.19 by Peltz, A., Volterra, J., Delle, A., and Streichenwein, F. presents urban case histories of blast vibration monitoring and offer that widely available off-the shelf monitoring equipment are not often used to their fullest potential and specified criteria and data interpretation efforts are often misunderstood, inadequate or incomplete. These issues perpetuate misunderstanding and unsubstantiated fear outside of the blasting community, into the wider engineering and construction disciplines and the public. Improvement in the means and interpretation of monitoring blast vibrations is achievable without incurring large additional costs.

The major project described in the paper was a new tunnel mostly constructed in schistose gneiss in lower Manhattan, New York, NY, USA. The excavation necessitated the removal of 59,000 m^3 (77,000 CY), 80% of which was removed by blasting. Up to 22 seismographs, triaxial velocity transducers from three different manufacturers, were used to monitor the project's adjacent urban infrastructure which included adjacent active subway tunnels and a signal (electronic relay) room, historic and newer buildings, and a vehicular tunnel. Vibration monitoring criteria ranged from 50 mm/sec [2 inches per second (ips)], to 12 mm/sec (0.5 ips) to 5 mm/sec (0.2 ips) for different structures along the alignment.

198 days of blasting included 1,679 individual blasts with more than 8,500 peak particle velocities recorded. The project included successful blasts performed within a meter (3 ft or less) of structural elements of adjacent active subway tunnels, the signal room and the temporary minipiles installed to underpin the subway tunnel during construction of the new tunnel which crossed beneath the original alignment.

Both active and passive vibration mitigation techniques were implemented, including line and channel drilling but also installation of isolation elements on the racks that held the sensitive electronic relay switches controlling signals in the subway tunnel. Automated text notifications to the field Engineer's phone within seconds of the blast were implemented for recorded events above a safe pre-established threshold value.

The authors present the added value in reviewing the time histories of blast records (full waveforms as opposed to histograms or reported peak values only) to verify the recorded values and support frequency based criteria and peak component (longitudinal, transverse and/or vertical) over the more typical maximum peak vector sum alone. Consideration or comparison of the natural frequencies of the adjacent structures to the dominant frequencies of the blast is critical to understanding the likelihood of damage to the adjacent structures.

Relatively inexpensive upgrades of standard and typical velocity transducers to high-frequency geophones or accelerometers can provide "cleaner" data in which to evaluate the time history of blasting records, especially in the near-field. As a function of the geometry, close examination of time histories can enable the blaster to evaluate individual detonations of the blast to improve the efficiency of rock removal for a given blast, or alternatively, to troubleshoot what happened in the event of a peak vibration above threshold values. Review of waveforms can offer a peak into the performance of the shot. Often when the criteria are exceeded, the majority of the time history remains below the threshold values and this information may be helpful to the blaster in minimizing the potential for a repeat spike.

The authors promote good recordkeeping necessary to evaluate or interpret blast monitoring data. Distance measurements and the preparation of peak particle velocity versus scaled distance plots (incorporating the maximum charges per delay) are necessary to establish site-specific factors used to better predict vibrations for subsequent blasts.

Much of the literature upon which common criteria are based are from large strip mining blasts performed by government agencies in the 1960's and 1970's in which the closest structures, one to two-story timber framed houses with plaster interiors, were hundreds of feet away or more. Technological advancements both on the blasting side and on the monitoring side should provide a better understanding of blasting procedures, an improvement in the criteria, documentation, data collection and interpretation. Often and in practice however, the equipment mobilized is underutilized, the criteria are inadequate and/or the data interpretation are lacking which perpetuates the perception that blasting is not well understood, that it is unmanageable and that progress is slow.

Paper #4.20 by Vlad, I., Vlad, M. N. titled "Case Study of Annoying Vibrations Generated by Unbalanced Forces of an Offset Printing Press" presents a case history in which a second hand large printing press showed excessive vibrations above 40 KIPH (print rate). This caused malfunctioning of the machine and annoying vibrations transmitted through the supporting floor of the press and through the entire industrial building. Relevant design data for the machinery were not available. The machine rested on a mat foundation with a length of about 33.2 meters (110 ft) and a width of 2.8 meters (9 ft). The ratio of the weight of the printing press to the weight of the foundation was approximately 1 to 1.5. Site soil consisted of organic matter for the first half meter (2 ft), followed by reddish brown firm to hard clay layer to 2.7 meters (9 ft), underlain by firm silty-clay to a depth of 45 meters (16 ft) with silty-clay to clayey-silt grading to sandy-gravel below. The water table was located at 6.5 meters (21 ft) below surface with fluctuations of ±1 m (3 ft).

In-lieu of data regarding unbalanced dynamic forces, the authors instrumented the press and its foundation. After recording the ambient vibration levels, they operated the press at varying printing speeds of 5 KIPH, 10 KIPH, 20 KIPH, 30 KIPH, 40 KIPH and 55 KIPH while collecting vibration data through sensitive seismometers at each printing speed. The main objectives of the study were as follows:

- Establish Eigen dynamic characteristics of the mat foundation with the press not operating.
- Collect data at various operating speeds in order to detect the speed at which the excessive vibrations occur.
- Collect dynamic data when the press started and stopped.
- Identify the source of excessive vibrations and recommend the most appropriate solution.

Data were collected via KINEMETRICS SS-1 Ranger seismometers and analyzed by DASYLab. Despite the manufacturer's claims that there were no "unbalanced" loads, detailed evaluation determined that the ink distributor rollers located on the machine were generating a transverse excitation as a function of the printing speed of the press.

The authors proposed three independent solutions:

- Replace the ink roller gears such that the frequency of the new rollers should be 60% less than the frequency of the first natural frequency of the system.
- Restrict the printing speed to less than 40 KIPH.
- Remove the existing rigid insulator between the press and the mat foundation and install in its place an adequate protection screen.

Paper #4.21 by Gatmiri, B., Mirlatifi, S. A., Keyvanpazdoh, K. titled "Retrofitting of the Compressor Foundation by Cement Grouting" presents a case history and remedial measures on excessive vibration problems of a K10-type compressor in a petrochemical complex. The compressor rested on a piled mat foundation of 20 x 20 x 4.5 meters (65 x 65 x 15 ft) with the maximum horizontal load of 1,800 kN (200 tons) at the top of the mat foundation with a frequency of 3.3 Hz and a maximum vertical harmonic load of 450 kN (50 tons) oriented or skewed at 45 degrees. Concrete piles were 0.4 x 0.4 x 23 meters (1.5 x 1.5 x 75 ft) vertical and inclined with a center-to-center spacing of 2 meters (6.5 ft). The maximum displacements that were experienced with the working machine were exceeding the specified value of the manufacturer.

A geotechnical pilot investigation was used to gather data necessary to establish soil parameters before and after the cement grouting operation which was proposed and eventually undertaken to stiffen the ground beneath the machine foundation. Data and analysis suggested that the grouting operation increased the soil stiffness (moduli) by a factor of five or more.

Using Plaxis, the authors established a two-dimensional dynamic finite element plain strain elastic model with absorbent boundaries to predict displacements of the foundation after cement injection. Parametric studies (varying Poisson's ratio and soil dynamic elastic moduli) were conducted for the pre-grouting condition until the model's estimated displacements matched those measured.

The authors used the model to establish the depth of ground improvement needed. The grouting program reduced the displacement amplitude of the machine by improving the foundation soil. Elastic moduli of the pre- and post-treated soils were estimated from geotechnical investigation and elastic theorem, respectively. The authors concluded that:

- Cement injection can be an expeditious and low cost measure of reducing foundation vibrations, though the potential for ground heave must be considered.
- Finite element methods are capable of predicting displacements from vibrations but iterative model verification and calibrations with reliable in-situ measurements are necessary.

Paper #4.22 by Sreekala, R., Lakshmanan, N., Muthumani, K., Gopalakrishnan, N., Sathishkumar, K. titled "Potential of Vibration Studies in the Soil Characterization around Power Plants – A Case Study" presents a case history of vibrations arising from power plants and their attenuation with distance due to material and geometric damping. The investigation was experimental and carried out on two diesel power plants, both running on the same frequency of 8 Hz. The ambient vibration data were collected using accelerometers connected to a Fast Fourier analyzer. Measurements were carried out on four outwardly radiating lines from the generating plant at 10 meters (33 ft) intervals.

The authors present that the Raleigh waves tend to be the most problematic when considering nearby structures, and that these waves attenuate through geometric and material damping. Geometric damping occurs when a constant amount of vibration energy travels into an ever increasing area of the progressing wave front. Material damping is related to the ground properties and vibration amplitude.

Vibration attenuation through the soil was found to follow the Bornitz equation which accounts for both geometric and material damping and contains coefficients for both phenomena. The authors also reviewed several studies by others which consider vibration attenuation through soil with distance and sources for estimating these coefficients for different soil types.

In-situ soil vibration measurements were collected at two sites, at 10 meter (33 ft) intervals from 15 meters (50 ft) to 100 meters (330 ft) from the plant, showing dominant frequencies equal to the operating frequency of the plant. The authors present measured versus calculated vibration attenuation curves (displacement versus distance) for vertical, east-west and north-south directions. The measured vertical amplitudes attenuated less than the lateral amplitudes. The authors then present the range of coefficients they observed with those reported in previous studies.

Paper #4.24 by Vlad, I. titled "Case History of the Malfunctioning of a "Compressor-Foundation-Supporting Soil" System" presents a case history related to the interaction of a compressor, its concrete block foundation and the supporting soil system. The compressor (type 06-NK3), located at an oil refinery in Romania, had a requirement of peak-to-peak limiting displacement amplitude of 63.5 microns and was installed on a concrete footing with dimensions according to the manufacturer's suggestions. Shortly after operations began, excessive vibrations put the machine out of service.

The designer used the results of an existing geotechnical study, conducted at 60 meters (200 ft) distance from the foundation. The basic elements for an analysis of the foundation with respect to dynamic forces were not available. Further, recommendations to remove known existing obstructions and to drain groundwater from beneath the proposed foundation were not carried out in the construction phase.

The author implemented two stages of data collection and extensive analytical evaluation to define the causes of the vibration problem. In the first stage, in-situ performance measurements were obtained to establish the dynamic properties of the foundation, including the displacement amplitude when the machine was operating at idle speed. Data were collected via KINEMETRICS SS-1 Ranger seismometers and analyzed by DASYLab. Upon a detailed instrumented investigation and evaluation, the author concluded that:

- Although the manufacturer provided the primary and secondary frequencies as 6.18 Hz and 12.36 Hz, the foundation was designed for the first frequency, and the dominant frequency was found to be close to the second natural frequency: 12.45 Hz.
- During the measurements, peak-to-peak amplitudes were measured as 121 microns, exceeding the manufacturer limitations of 63.5 microns.
- Remedial measures were proposed but the owner initially did not consider them in favor of a less expensive alternative of enlarging the concrete footing.

The author conducted another set of measurements after the enlargement of the foundation with the following objectives in mind:

- Compare data to that collected from the previous investigation.
- Find the characteristics of the foundation motion considering its six degrees of freedom.
- Derive motion parameters to verify the validity of the numerical analysis.
- Obtain supplementary information for developing a solution to the problem.

The measurements in the second stage yielded peak-to-peak displacement of 73 microns at idle speed of the machine. Following theoretical evaluations and additional site investigation, the underlying mechanism for the excessive vibrations was described. Foundation enlargement changed the amplitudes of the motions along the six degrees of freedom, but it did not alleviate the excess vibrations. Two other compressors were in operation in the vicinity of the compressor of interest, complicating the interpretation. Hence, interactions among all three compressors existed, which contributed adversely to local vibration transmissibility.

The author has concluded that the owner eventually accepted the necessity of a complete redesign of the foundation, for which details are not yet available.

Paper #4.25 by Dey, K., Pal, B. K. titled "Ground Vibration – Unique Case Studies in Indian Coal Mines" presents a case history of an investigation in the coal mines of India on prediction of ground vibrations arising from explosives. As shallow coal reserves are depleted and demand increases, the greater challenge of safely mining deeper coal seams has prompted a review of the means and methods of controlling blast vibrations without compromising productivity.

The authors present a literature review of numerous parameters which affect the peak particle velocity (PPV) resulting from a blast. After reviewing available equations to estimate PPV, the authors proposed equations to estimate the ground vibration levels considering hole to hole delay blasting versus row to row delay blasting and they consider, compute and evaluate both the maximum charge per delay and total charge weight for each.

A total of 19 blasts were instrumented, of which 11 included hole to hole delays and eight included row to row delays. Instrumentation consisted of two Minimate Plus seismographs manufactured by Instantel Inc.

Numerous tables and graphs of subsurface conditions are provided (including rock properties, bench heights, thicknesses, joint sets details, dip/direction, point load index and compressive strength). Blast parameters are tabulated (maximum charge per delay, total charge, PPV, and square root scaled distance calculated using both pounds per delay and total pounds used) and resulting comparisons of peak particle velocities versus square root scaled distance are provided. For reference, maximum charge sizes ranged from 95 to more than 1,300 kg/delay (210 to more than 3,000 lbs/delay), with total charge weights up to 14,500 kg (32,000 pounds).

The researchers reported that the vibration levels were lower for the row to row blasts than for the hole to hole blasts at the same square root scaled distance for both maximum charge per delay and total charge weight detonated. This was contrary to common perception that the use of delays to separate the blast into several smaller detonations reduces ground vibrations. The authors have postulated that the blast initiation direction and resistance of the materials to breaking may have played a significant role in their observations. They recommend additional investigations.

Table 1. Session 4 Papers

Paper Authors	Paper Title	Key Words	Summary of Content	Approach	Country
#4.01 Hayakawa, K. Nakaya, I. Nisimura, T.	The Spread Phenomenon of a Low Frequency Ground Vibration to Originate in the Highway Bridge and its Simulation Analysis	Vehicular vibrations from bridge to adjacent properties	Trucks on multi-span elevated bridge structure cause vibrations at natural frequency of nearby houses. Measurements were collected and presented.	Field instrumentation, measurements and theory, two-dimensional finite element	Japan
#4.02 Nakaya, I. Hayakawa, K. Kashimoto, T.	In-Site and Model Experiments about Ground Vibration Isolation Method by using Scrap Tire	Vibration Isolation/ Degradation, Recycling Scrap Tires	Full scale in-situ and model test barrier walls formed using crushed recycled scrap tires encapsulating pipe piles used as a means to degrade vibrations.	Vibration propagation/ attenuation, wave motion theory	Japan
#4.04 Studer J.A. Panduri, R. Höltschi, H.P.	Synchrotron Facilities: Meeting Stringent Deformation and Vibration Criteria	Machine Foundations, Vibration and Deformation Tolerances, Dynamics	Foundation design and considerations for large machine type testing facility at two geologically different sites and discussion of means to minimize vibrations and deformations.	Geologic subsurface investigations, field measurements, vibration isolation and damping, foundation design	Switzerland
#4.05 Fiegel, G. L. Farrell T. M.	Measurement of Vibration and Noise During the Installation of Rammed Aggregate Piers	Rammed Aggregate Pier Installation Noise and Vibrations	Construction noise and vibration monitoring data collected between 1 and 10 meters from the hammer during pier installations and comparisons of measured data with typical published construction vibrations.	Field measurements during pier installation, vibration and noise attenuation, rammed aggregate piers	USA
#4.06 Biringen, E. Davie, J.	SPT Automatic Hammer Efficiency Revisited	Standard Penetration Test N-Value, Energy Transfer Ratio, Field Investigations	Review of the background, theory, justification and method of measuring energy transfer from hammer to drill rods and correcting blow counts to standardize input parameters for geotechnical design. Field measurements are presented.	Field measurements, energy correction	USA
#4.08 Li, Z. M. Lin, J.H	A Case – Vibration Influences and its Evaluation in Muck Ground Improvement with the Static-Dynamic Method	Static-Dynamic Drainage Consolidation Method, Tampers, Vibrations, Soil Improvement	Introduction to SDDCM and efficiency comparison of four drop weights. The authors examine the impact stage to improve the energy transfer while reducing transmitted vibrations to achieve rapid settlement in thick soft organic clays.	Field measurements, energy maximization, work platform, wick drains, dynamic compaction, consolidation	China

Table 1. Session 4 Papers (Continued)

Paper Authors	Paper Title	Key Words	Summary of Content	Approach	Country
#4.09 Tajirian, F. Tabatabaie, M. Asiri, F. Seryi, A.	Calibration of Computer Program SASSI for Vibration Transmissibility Analysis in Underground Structures using Field Measured Data	Vibration Attenuation, 3-D Finite Element Computer Modeling, Tunneling	The authors setup a 3-D finite element model, collected field measurements and varied the location of the impulse force from ground surface to within the tunnel. They collected and modeled vibration attenuation at grade and within each tunnel and examined impulse force, maximum velocity, mobility and peak displacement.	Field instrumentation and measurements to calibrate and verify three-dimensional finite element program SASSI	USA
#4.12 Zheng, W.	Large Pile Group Design Optimization with Lateral Resistance of Pile Cap	Deep Foundation Pile Group Design, Lateral Capacity, LPILE	The author presents a comparison of United States and Chinese methods of computing lateral pile group capacities and presents a method to increase the capacity by optimizing the spacing along the short side of strip-shaped pile caps. A case history is presented where the number of piles was reduced by 15%.	Field instruments and measurements, lateral pile design capacity and lateral load testing, LPILE computer modeling	USA
#4.16 Halabian, A. M. Hashemolhosseini S. H., Rezaei, M.	Nonlinear Seismic Analysis of Buried Pipelines During Liquefaction	Liquefaction Analysis, Buried Pipelines, Finite Element Analysis Modeling	An algorithm defining the hysteretic loops for liquefiable sands is presented for use in finite element models of pipelines in liquefiable sands during an earthquake event. The hypo-elastic model incorporates soil cyclic nonlinear behavior of sands during liquefaction.	Finite Element computer modeling, hypo-elastic nonlinear modeling.	Iran
#4.17 Hempen, G. L.	Destructive Water-Bourne Pressure Waves	Marine Engineering, Sonic pressure wave transmission, attenuation	Energy sources (e.g. blasting, pile driving and seismic exploration) in or near a water body can produce pressure waves that negatively impact water-side structures and fauna. Methodologies to reduce the severity of these negative impacts and to address these issues in the design stage are presented.	Wave propagation theory, pressure wave barriers, air bubble curtains	USA

Table 1. Session 4 Papers (Continued)

Paper Authors	Paper Title	Key Words	Summary of Content	Approach	Country
#4.18 Arsoy, S.	Mitigation of Adverse Vibrations in nearby Structures arising from a Large Forge Hammer	Machine Foundations, Dynamics	Rehabilitation of support for an active machine accomplished by reducing the number of springs between the foundation and the machine, thereby reducing the foundation amplitude and increasing the machine's amplitude.	Reverse vibration absorber approach, vibration attenuation, isolation, field instrumentation and measurements	Turkey
#4.19 Peltz, A. H. Volterra, J. L. Delle, A. Streichenwein, F.	Urban Blasting Vibrations: Case Histories of Vibration Monitoring in New York City	Blasting, Vibration Monitoring, Data Interpretation	Reviews methods for using blast monitoring equipment and data to fullest potential to interpret and evaluate blast performance. Describes oversights commonly observed in practice and basis for commonly specified criteria. Suggests additional studies.	Field instrumentation and measurements, vibration monitoring, scaled distance, full waveforms	USA
#4.20 Vlad, I. Vlad, M. N.	Case Study of Annoying Vibrations Generated by Unbalanced Forces of an Offset Printing Press	Machine/ Printing Press Foundations, Dynamics	Investigation, alternatives and solution for reducing excessive vibrations of a large printing press during its operation at high speeds. The authors measured and established natural frequencies under various operating conditions, identified the vibration source and recommended a solution.	Field instrumentation and measurement, vibration isolation	Romania
#4.21 Gatmiri, B. Mirlatifi, S. A. Keyvanpazdoh, K.	Retrofitting of the Compressor Foundation by Cement Grouting	Machine/ Compressor Foundations, Dynamics, Remedial Grouting, 2-D Finite Element Modeling, Ground Improvement	Remedial grouting for excessive vibration problems of a pile foundation supported compressor. The authors setup a dynamic finite element plain strain elastic model with absorbent boundaries and use it to predict the reduction in vibrations from the machine foundation from before to after grouting.	Field instrumentation and measurements, ground improvement	Iran

Table 1. Session 4 Papers (Continued)

Paper Authors	Paper Title	Key Words	Summary of Content	Approach	Country
#4.22 Sreekala, R., Lakshmanan, N., Muthumani, K., Gopalakrishnan, N., Sathishkumar, K.	Potential of Vibration Studies in the Soil Characterization around Power Plants – A Case Study	Machine/ Power Plant Foundations, Bornitz Equation, Radial/ Geometric and Material Damping	Vibration attenuation measurements with distance from two power plants operating at 8 Hz collected using accelerometers and a Fast Fourier analyzer on four outwardly radiating lines at 10 meter intervals (33 ft). Vibration attenuation followed the Bornitz equation, and previous studies of vibration attenuation by others were presented.	Field instrumentation and measurements, vibration attenuation	Iran
#4.24 Vlad, I.	Case History of the Malfunctioning of a “Compressor-Foundation-Supporting Soil” System	Machine/ Compressor Foundations, Motion Equations	Reports on the interaction of a compressor, its concrete block foundation and the supporting soil at an oil refinery. Available geotechnical information was inadequate. Vibration measurements at an array of sensor locations were collected before and after a concrete footing expansion. Extensive theoretical analysis led to a joint decision to completely redesign the footing.	Field instrumentation and measurements, vibration attenuation, wave motion theory, remedial measures	Romania
#4.25 Dey, K. Pal, B. K	Ground Vibration – Unique Case Studies in Indian Coal Mines	Blasting, Vibration Monitoring, Data Interpretation	The authors present data that suggest a row to row rather than a hole to hole blasting sequence may be more effective at reducing vibrations at the same scaled distance from the blast. They compared data using both maximum pounds per delay and maximum charge weight, contradicting earlier research and widely accepted understanding on the subject matter.	Field instrumentation and measurements, vibration monitoring, scaled distance, delay sequence, charge per delay	India

CLOSING REMARKS / DISCUSSION TOPICS

The authors of this General Report would like to take this opportunity to express gratitude towards Dr. Shamsher Prakash, the organizing committee and the individual authors of this section, for your confidence in allowing us the opportunity to prepare this General Report and to summarize these papers. It was needless to say, a humbling experience to be challenged with reading, comprehending and then summarizing these cumulative works, many of which represent more than a summary of a single case history but that incorporate years of professional practice, theory and research. Knowing the effort it takes to complete a technical paper, this General Reporter now fully appreciates the effort required to fulfill the requirements of the General Reporter and looks forward to presenting these subjects at the conference and assisting in a the discussion that follows.

We have attempted to summarize these subjects without misinterpreting or misrepresenting any of the objectives and purposes of each individual author's efforts. We encourage every reader of this General Report to read in entirety, the full texts of each of the individual papers for which they have an interest, and to rely solely on the words of the authors as opposed to the brief summaries contained herein.

Possible Discussion Topics

Quality Geotechnical Investigations

In general terms, many authors discuss the need for quality geotechnical investigations as they relate to dynamics in foundation engineering and vibration problems. While this would appear an obvious need, it is also understood that this problem is one that will likely never disappear from our practice as there will always be engineers who do not specialize in vibration problems that may not understand the consequences of their actions in the design stage. Better communication advantageous and is promoted, and there are many more available resources to the practicing engineer in the field of machine foundations and vibration problems than there were even a decade ago.

Computational Methods

Are the available finite element models sufficient and user friendly enough to accommodate the types of projects and geometries that are most often encountered in practice? Are there sufficient checks and balances in the programming routines that allow for independent sanity checking of the input parameters and modeling assumptions?

Demystifying vibration problems

In practice, there remains some confusion or fear of some vibration problems. Projects containing explosives, designs requiring matrixes, degrees of freedom, Fast Fourier or spectra response, coordination between owner, manufacturer, contractor and designer, advanced computer analysis requiring three-dimensional finite element or other soil-structure interaction models often instill caution in general practitioners who do not engage in these services on a regular basis. Advancement of the practice through case history conferences, continuing education, in-house seminars and peer reviews can all assist to demystify these and other related concerns. We should encouraging interaction between practicing engineers and universities or their students looking for research opportunities. Can we as a group construct a prioritized list of needed research opportunities and can the practitioners in the group provide the necessary new case histories and data from which these studies can be based?

Current state of Case Histories Described

Several of the case histories detailed in this session were still in progress at the time of writing, and several mentioned potential fixes that had not yet been implemented. It would be interesting to follow up on those that were not yet resolved as of the time of writing, to see if authors can elaborate on the current state of those particular projects. In the case of many of the machine foundation fixes or new foundations designed for new facilities, how have these fixes or new foundations performed? Alternatively, in the case where foundation support or spring stiffness was varied, how have the machines performed under these new conditions and what has been the required maintenance, if any?

Available Monitoring Instruments

Are the widely available tools used to monitor vibrations and process the data adequately user-friendly, robust and used to their potential? Is there in practice, sufficient training for field technicians if Engineers are not directly responsible for setting up and collecting the data for these complex problems? Do clients get the best data and interpretation of that data on a regular basis, or do cost constraints often diminish the quality of the information obtained? Are vibration monitoring criterion adequately specified and enforced? Will the near future include improved instrumentation and communication devices embedded in soils, foundations or mounted upon machines to provide improved feedback in real time to machine or facility operators and to thus reduce maintenance costs and annoying or damaging vibrations?

We look forward to the poster presentations of the numerous papers and the ensuing discussions with authors, practitioners, educators, researchers and other conference attendees.

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