13 Mar 1991, 1:30 pm - 3:30 pm

Session 11: Discussions and Replies

Multiple Authors

Predicting Vibrations of Soils and Buildings Excited by Machine Foundations under Dynamic Loads by Mark Svinkin, Paper no. 11.1
Discussed by Paul Hölscher, Project engineer, Delft Geotechnics, Delft, the Netherlands

Svinkin presents an experimental method to predict vibrations of planned structures induced by near by dynamically loaded machine foundations. The method is based on in-situ measurement of the response on a shock load (impulse). The soil behaviour is assumed to be linear. The prediction holds for distances more than 7 times the (equivalent) radius of the exciting foundation.

The analytical approach is vague and an (english) reference is missing. This means it is difficult to understand the method of prediction.

It is worthwhile to concentrate on the experimental investigation. Some predictions are compared with field measurements. Based on the presented figures, good agreement is obtained. This means a valuable procedure is presented.

This conclusion is based on 13 testsites, but the paper shows results of only one testsite. A tabulated summary of the results of the other 12 sites would support Svinkin's conclusions. This table should contain the predicted and measured displacements and the soil conditions on the site. Using this table, one can calculate the absolute and relative errors for this method and estimate the range of application more accurately.

DISCUSSION BY
T.S. THANDAVAMOORTHY, ASSISTANT DIRECTOR,
STRUCTURAL ENGINEERING RESEARCH CENTRE,
MADRAS, INDIA, ON
"PREDICTING VIBRATIONS OF SOIL AND BUILDINGS EXCITED BY MACHINE FOUNDATIONS UNDER DYNAMIC LOADS"
BY
MARK SVINKIN,
KILROY STRUCTURAL STEEL CO.,
CLEVELAND, OHIO, USA

Paper No.11.1

The author should be congratulated for presenting an excellent method of predicting the ambient vibration level of soil in the vicinity of a proposed machine foundation before its actual installation.

The suggested method will help the design engineer know beforehand the vibration level expected at a particular site after the installation of the proposed machine foundation and also in suitable planning of the location of sensitive units.

The proposed method consists of the experimental determination of the impulse response of soil at a particular point of site of interest due to the application of impact directly on soil at the place of installation of the machine foundation. The analytical approach for the prediction of the expected vibration of the soil is based on Duhamel's or Fourier integrals. Prediction of soil vibration has been done for machine foundations of different foundation areas and depths and also for various types of excitations, viz., impact and harmonic loads. Experimental values have also been collected and presented. Both analytical and experimental results are presented in the form of vibrograms. Good agreement has been found between experimental and predicted values.

In the experimental determination of the impulse response of the soil, the impacts are directly delivered on the soil. This is quite likely to result in large-amplitude dynamic strains in the soil and this may cause changes in the soil structure which result in the loss of strength in soil mass. The effect of these large-amplitude dynamic strains on the elastic waves transmitted in the soil and its effect on soil vibration need clarifications.

The conclusion that the dimensions of the foundation have little effect on the amplitude of soil vibration at distances more than 10 - 30 metres from the foundation C.G. is not convincing especially when, in Eq.(3), foundation area A and the natural frequency of vertical vibration of foundation, which depends again on the foundation area, figure dominantly.

DISCUSSION ON
PREDICTING VIBRATIONS OF SOIL AND BUILDINGS EXCITED BY MACHINE FOUNDATIONS UNDER DYNAMIC LOADS
BY
MARK SVINKIN
(PAPER NO.11.1)
BY P. SRINIVASULU, SENIOR SCIENTIST
STRUCTURAL ENGINEERING RESEARCH CENTRE,
MADRAS, INDIA.

The author has explained a method of experimentally evaluating the expected response at a given distance from a machine foundation of given characteristics and compared it with actual response for some cases. The author could have explained atleast one typical case more exhaustively to appreciate the trend of results both by predictive calculations and actual vibration measure-ments. The use of impulse response functions is well known in structural response predictions. But in the case of wave propa-gations through complex soil media, the use of linear theory and the dependance of end results on various variables involved can at best, give a broad trend of response at a desired location away from a given source of disturbance.

It is however desirable to get the following clarifications from the author on the contents of the paper:

1. Savinov's method of estimating C_z may be explained atleast in brief for reader's information.

2. The terms like "Seismographs VAGIK" and "GB Galvanometers" are not clear.

3. How is the "modulus of damping (ϕ)" defined? Its units are stated as "seconds". How is damping assumed in the predictive calculations of soil vibrations for foundations with varying base areas or depths of embedment? The latter is known to be a more influencing parameter on damping.

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Discussion by T.S. Thandavamoorthy, Assistant Director, Structural Engineering Research Centre, Madras, India, on "Pile Driving Analysis: Two-phase Finite Element Approach" by P. Hölscher, Delft Geotechnics, P.O. Box 69, 2600 AB Delft, The Netherlands

Paper No.11.4

The author should be congratulated for presenting an interesting paper on the numerical simulation of a pile-driving process taking into account the realistic situation. This paper presents a new in-sight into the behaviour of soil around a pile under dynamic loading.

While an attempt has been made to explore the possibilities of the application of continuum approach using finite element, the influence of a more realistic situation of soil layering could have been attempted in this investigation, since many studies have been carried out to predict the response of pile-soil system including layering effect.

Many investigations have been carried out to predict the response of pile-soil system under dynamic situations, assuming perfect bond between pile and soil. But the works of Novak (1980), Lakshmanan (1981), and Srinivasulu et al (1982) have laid an emphasis on taking into account the pile-soil interface and the effects of radial non-homogeneity of soil on the dynamic soil reactions. The present study by the author strengthens the above approach and the findings reported may be quite useful in the determination of the dynamic soil reactions.

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Paper No.11.5

The authors should be congratulated for proposing a rational approach to assess the damage caused by ground vibrations based on wave propagation theory and also taking into account the interaction of structures with the ground as many of the criteria in existence now especially related to blasting were arrived at ignoring the structure. The various aspects of structural damage such as the sources of vibration, the factors causing damage, mechanism of damage, and the damage criteria have all been reviewed quite elegantly. The deficiency in the provisions relating to vibration criteria of various existing codes has been brought to light. The dependency of these damage criteria on the local soil condition has been emphasised.

A similar concept has been expressed by By (1986), while presenting an overall view on the Norwegian practice on blasting vibration phenomena with regard to damage criteria and ground vibration limits in urban areas. By has concluded that safe vibration levels can only be given after a ground and structural dynamic analysis, since the ground and structural response are highly frequency dependent.

Equations to calculate the vibration criteria proposed by the authors are quite useful for design engineers and these equations are rational as they take into account the type of vibration source, building category, and degree of damage.

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Dis?ussion on

"Damage Criteria for Small Amplitude Ground Vibrations"

By k.Rainer Massarsch, Bengt B.Bromc.
Paper No. 11.5

Xian-Jian Yang. Senior research Engineer, Professor,

4th Design & Research Inst. Ministry Machinery and Electronics Industry P.R.CHINA.

Analyses on Damage of Building Caused by Small Amplitude Ground Vibration

Building damage caused by base soil dynamic settlement. The authors point out that ground distortion caused by static and dynamic loading on soil is the primary factor leading to damage of buildins's structure. This discussion paper suggests that the shear modulus Gs under the dynamic shear strain of base be used to quantify the damage of base as is shown below,

$$Gs=Go[1-(\frac{\varepsilon_m}{\varepsilon_o})^n].\cos\theta \qquad (1)$$

where , Go---- Shear modulus of base when $\varepsilon_m=10^{-6}$.(S.Prakash,1981)
ε_o-----Maximum dynamic shear strain when unsteady settlement of base takes place, for sand soil, $\varepsilon_o=10^{-3}$(Jr.Richart, 1977, Y.Z.Xu. 1985); for Saturated clay soil, $\varepsilon_o=10^{-2}$ (J.F.Xie,1974);
θ-actual tilting angle when it is tilting, for common horizontal ground, $\theta=0$; n=0.5 for sand soil and n=0.35 for saturted clay soil.

Building Damage caused by Wave Motion.

For largesized building, Cave and the ancient building of which the material of constrution has very low wave velocity, the propagation time of stresses wave in the direction of the action of wave motion is probably greater than the incident time of stresses wave. In this case, it is not proper to analysis according to dynamic response, but the wave motion effect should be considered. The authors report when the wave length of builgings is equal to or less than that of incident wave, the damage potertial is greatest. This can be verified by "coincident effect of wave" (x.j.yang,1991), and so the incident angle of incident wave should also be considered.

Effect of Building Foundation on Ground Vibration.

The vibration under building foundation is generally smaller than that of free ground. This is because the period of building is usually bigger than that of ground . The following equation can be used for this,

$$Vv=\beta Vf \qquad (2)$$

where , β=0.4~0.60 ; Vf----particle velocity of free ground.

Reference

Shamsher Prakash, Soil Dynamics, McGraw-Hill Book Company 1981.

Xian-Jian Yang, Proc. Second Int. Conf. on Recent Adv. in Geot. Earth. Engr. and Soil Dyn. March 11-15, St. Louis 1991. p.p.1557

DISCUSSION ON

"DAMAGE CRITERIA FOR SMALL AMPLITUDE GROUND VIBRATIONS"

BY K. RAINER MASSARSCH AND BENGT B. BROMS

PAPER NO. 11.5

**BY LARRY P. JEDELE, SENIOR PROJECT CONSULTANT
SOIL AND MATERIALS ENGINEERS, INC.
LIVONIA, MICHIGAN**

The authors recognize the broad variations which exist between existing vibration damage codes and standards for structures within the European community. These standards are typically based on correlating measured vibration levels with observed damage to structures and are influenced by local soil conditions. As a result of this disparity, the purpose of this paper was to narrow the gap between these European standards and provide a uniform method of evaluating structural damage due to vibration. The authors propose an approach which incorporates traditional information (vibration levels and observed damage) along with dynamic soil characteristics, based on the wave propagation theory.

The authors point out that ground distortion caused by static and dynamic loading is the primary factor leading to damage of structures. As a result of vibrations, the structure is subjected to a series of sagging and hogging cycles. The severity of the damage which occurs is dictated by the wave length of the vibration which is a function of the wave propagation velocity and the vibration frequency. The authors report when the wave length is equal to or less than the length of the structure, the damage potential is greatest.

Since the damage which could occur to a structure from vibrations is dependent on the nature of the vibration source, the dynamic soil characteristics and the type and age of the structure, the authors propose a simple formula for determining the vibration level which incorporates these factors along with the amount of damage. The computed results from this formula compared remarkably well with data in the literature. However, the suggested coefficients used in the formula should be further reviewed and adjusted accordingly.

The authors are also cognizant that buildings supported on loose and/or saturated sands and silts are subject to settlement due to vibrations and that cracks can develop from thermal or humidity changes and freeze-thaw cycles.

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By
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(Paper No.11.5)

by Mark Svinkin, Kilroy Structural Steel Co.
Cleveland, Ohio.

The authors reviewed European codes and found considerable divergence between vibration threshold levels for different codes. It was suggested a rational approach to evaluate the damage from ground vibrations based on using the length of propagating wave. Equation for the critical deflection ratio was obtained for vertical soil displacements in the direction of the wave propagation. The ground distortion is depended on two ratios, the length of the building to the length of propagating wave and the soil velocity to the wave propagation velocity. In order to predict the maximum permissible vibration levels of dynamic ground distortions it was derived an expression for the critical vertical vibration velocity of soil. Authors have considered the extreme case when the length of the building corresponded to half the wave length.

The suggested expression can be used at the frequency range of 20 Hz to 50 Hz for same distance from vibration source. In this connection I would like to draw author's attention to the following: 1) Foundations under machinery with vertical impact loads have natural frequencies within 3 Hz to 20 Hz. Moreover, independently from vibration source soil vibrations with high frequencies damp very quickly. Therefore those vibrations can be neglected on some distance from wave source and the real frequency range will be displacing in the direction of lower frequencies. 2) It was shown experimentally that dynamic settlements and dynamic forces from operative bridge cranes caused damage of structures of forge shops where influence of impulse loading is the strongest. This remark have been done because in the paper the expression for critical velocity had been suggested for severe degree of damage to structures as well. 3) It is very important how the buildings are placed relatively to the wave front.

Authors have shown interesting, useful results, but it is desirable scope of them application should be defined more precisely.

DISCUSSION ON

"GROUND VIBRATION ISOLATION USING GAS CUSHIONS"

BY K. RAINER MASSARSCH

PAPER NO. 11.6

BY LARRY P. JEDELE, SENIOR PROJECT CONSULTANT
SOIL AND MATERIALS ENGINEERS, INC.
LIVONIA, MICHIGAN

Our appreciation is expressed to the author for sharing with us a new ground vibration isolation method using inflated flexible cushions installed vertically in trenches filled with cement-bentonite grout. Previously, either open trenches or trenches filled with a material differing with the surrounding soil were used for isolation systems for structures or equipment which could be adversely affected by vibrations. Typically, the open trenches proved to be most effective, reducing the vibrations roughly to about 25 percent of the non-isolated level for trench depths equal to about one wavelength.

The so-called "gas cushion screen" was initially developed in Sweden about 10 years ago. The cushion can be installed in a slurry trench to depths dictated by the limitations of the slurry equipment. Once in place, the cushion is inflated and the slurry is displaced with a self-hardening cement-bentonite grout. In addition to discussing the installation procedure, the author presents the theory behind the performance of gas cushions as an isolating medium.

Two case histories were presented. The isolation efficiency of the cushion material was evaluated. In one example, the normalized vibration amplitudes were presented as a function of frequency. The resulting patterns were as expected in that the lower frequency amplitudes generally attenuated slower than those at higher frequencies.

Due to the low impedance of the cushions, the author's test results indicate a favorable comparison with the open trench isolation system on the basis of the isolation efficiency. He suggests the cushion is effective at about 0.8 to 1.0 times the wavelength and therefore, the wave propagation velocity should be determined for the surrounding soil and the cut-off frequency for the structure.

The use of gas cushion isolation screens appear to show promise, especially in areas where it would be impractical to maintain an open trench to achieve the maximum isolation effect.

Discussion on
"Damage Criteria for Small Amplitude Ground Vibrations"
By
K. Rainer Massarsch and Bengt B. Broms
(Paper No.11.5)

by Mark Svinkin, Kilroy Structural Steel Co.
Cleveland, Ohio.

The authors reviewed European codes and found considerable divergence between vibration threshold levels for different codes. It was suggested a rational approach to evaluate the damage from ground vibrations based on using the length of propagating wave. Equation for the critical deflection ratio was obtained for vertical soil displacements in the direction of the wave propagation. The ground distortion is depended on two ratios, the length of the building to the length of propagating wave and the soil velocity to the wave propagation velocity. In order to predict the maximum permissible vibration levels of dynamic ground distortions it was derived an expression for the critical vertical vibration velocity of soil. Authors have considered the extreme case when the length of the building corresponded to half the wave length.

The suggested expression can be used at the frequency range of 20 Hz to 50 Hz for same distance from vibration source. In this connection I would like to draw author's attention to the following: 1) Foundations under machinery with vertical impact loads have natural frequencies within 3 Hz to 20 Hz. Moreover, independently from vibration source soil vibrations with high frequencies damp very quickly. Therefore those vibrations can be neglected on some distance from wave source and the real frequency range will be displacing in the direction of lower frequencies. 2) It was shown experimentally that dynamic settlements and dynamic forces from operative bridge cranes caused damage of structures of forge shops where influence of impulse loading is the strongest. This remark have been done because in the paper the expression for critical velocity had been suggested for severe degree of damage to structures as well. 3) It is very important how the buildings are placed relatively to the wave front.

Authors have shown interesting, useful results, but it is desirable scope of them application should be defined more precisely.

DISCUSSION ON

"GROUND VIBRATION ISOLATION USING GAS CUSHIONS"

BY K. RAINER MASSARSCH

PAPER NO. 11.6

BY LARRY P. JEDELE, SENIOR PROJECT CONSULTANT
SOIL AND MATERIALS ENGINEERS, INC.
LIVONIA, MICHIGAN

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The use of gas cushion isolation screens appear to show promise, especially in areas where it would be impractical to maintain an open trench to achieve the maximum isolation effect.

DISCUSSION ON

"TORSIONAL DYNAMIC RESPONSE OF EMBEDDED FOOTINGS"

BY PEIJI YU, F.E. RICHART, JR. AND E.B. WYLIE

PAPER NO. 11.7

**BY LARRY P. JEDELE, SENIOR PROJECT CONSULTANT
SOIL AND MATERIALS ENGINEERS, INC.
LIVONIA, MICHIGAN**

The authors presented a rigorous analytical solution for evaluating torsional dynamic response of embedded rigid circular footings. Up to the present time, the analytical solution was limited to only surface footings. Based on experience with surface footings, certain soil/foundation interaction features were applied to the embedded footing case which are discussed in this paper.

The analytical tool used for the analysis is a computer program which evaluates stresses and displacements below an axisymmetric footing subjected to torsional loading. The program incorporates a characteristic-like approach for solving the response of the footing to torsional loading. A discussion was presented on the theory behind the analysis.

The material surrounding the footing can be analyzed as elastic, nonlinear inelastic or nonlinear inelastic with slip along the perimeter and base of the footing. Based on information in the literature, the nonlinear and slip effects should be considered since variations in theory and test results occur when these things are ignored. Layered systems can also be analyzed.

The analysis of the elastic systems indicated favorable results when compared with published data obtained by finite element analyses or by approximate methods. Key parameters such as the maximum amplitude of rotation and the corresponding dimensionless frequency were correlated to the embedment ratio.

For the nonlinear inelastic case, the computer results were compared with a circular embedded footing tested in the field. The comparison indicated that nonlinearities in soil/foundation system affects the response of the footing and the corresponding stresses, strains and displacements in the soil. This confirmed the findings of previous studies that soil/foundation nonlinearities and slip must be included in the analysis to obtain a reasonable match with field results.

Discussion on "Pile Driving Criteria for Construction Near an Historic Dam" By L.P.Jedele (Paper No. 11.8)

by Mark Svinkin, Kilroy Structural Steel Co.
Cleveland, Ohio

Described investigations were implemented to determine pile driving criteria for construction of a new bridge near an historic dam. In my opinion the author have chosen the most rational and reliable way for the solution of this problem. The basic phase I investigation was done prior to the construction. This phase involved field vibration measurements for determining of maximum vibration levels of the Secord Dam from normal dam operations and the effect of the simulated pile driving test. Also natural vibration background was measured. The vibration analysis have resulted in measured vibrations at the dam were within the allowable levels for modern structures in good conditions, and also below the proposed damage threshold criteria for historic and older sensitive buildings.

The place for the simulated test pile was the closest planned location to the dam - 110 feet from the centerline of the earth embankment. The simulated pile driving procedure involved pre-drilling through the overburden to the clay hardpan. It should be marked that utilization namely of this pile driving procedure in combination with selection of demanded energy for test pile immersion have ensured vibrations of the dam at permissible limits. On the basis of those data it was computed a recommended maximum of energy for pile hammer to be used during installation of the bridge abutment piles. Unfortunately, author did not show the formulas for those analysis.

During the phase II investigation measurements of vibrations on the Secord Dam were made from driving of the production piles for construction of the new bridge located about 300 feet downstream from the dam. Obtained vibration amplitudes were within the limits determined at the phase I investigation. Pile driving criteria for construction near the Secord Dam have been grounded correctly. In conclusion, the author should be congratulated for the interesting, splendid paper.

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Pile Driving Criteria for Construction near an Historic Dam by L.P. Jedele, paper no. 11.8
Discussed by Paul Hölscher, Project engineer, Delft Geotechnics, Delft, the Netherlands

Jedele presents a comprehensive description of a field investigation. The investigation aimed to prevent that pile driving damages an historic dam near by. The investigation is divided in two parts: firstly a predictive one, and secondly a monitoring one.

The predictive investigation consists of a pile driving test near the historic dam. The resulting vibrations are compared with vibrations induced by the operation of the dam. All relevant data are presented. Based on the attenuation data the maximum pile driving energy is calculated (by extrapolation).

The monitoring investigation is carried out during the pile driving near the dam. The maximum pile driving energy was applied and the predicted vibrations were measured. This means the applied method is reliable.

The theoretical background of the method is beyond the practical scope of the paper. However, I think some information about the soil conditions and the path, along which the energy is transmitted, would increase the value of this paper. Then the use of a distance which is scaled on energy will be clearified too.

Discussion by T.S. Thandavamoorthy, Assistant Director, Structural Engineering Research Centre, Madras, India, on "Prediction of Vibrations of Footings for Highly Sensitive Devices" by Werner Palloks, Werner Heidrich and Stephen Achilles of Forschungsanstalt für Schiffahrt, Wasser-und Grundbau, Berlin, German Democratic Republic

Paper No.11.11

To design a foundation for highly sensitive devices in the vicinity of vibration sources is an uphill task especially when stringent regulations are to be satisfied. Towards this goal, this paper is a welcome addition. The authors have presented a well known experimental procedure for the in situ determination of the dynamic parameters of the half space as an exercise towards the estimation of vibration at the proposed site of sensitive devices. A similar procedure has been described in the Bureau of Indian Standards code IS 5249-1969 for the in situ determination of dynamic soil properties.

The calculation procedure presented in the paper has been developed on the assumption that there is no layering of soil. In a practical situation layering of soil is bound to be there. The effect of layering will be pronounced especially when the footing is embedded. When the derived transfer function is frequency dependent, with layering of soil, what would be the reliability of the predicted vibration level of the production foundation?

The statistical approach presented for stochastic excitation for the prediction of the probabilities of maintaining or exceeding the permissible values is quite a useful technique for a design engineer.

The recommendations presented for the minimum admissible distance, even though based on limited test results and homogeneity of soil medium, are quite useful and they may form a preliminary guide for the estimation of the vibration level.

The authors are commended for sharing the case histories concerning vibrations.

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Prediction of Vibrations of Footings for Highly Sensitive Devices by Werner Palloks, Werner Heidrich and Stephan Achilles, paper no. 11.11
Discussed by Paul Hölscher, Project engineer, Delft Geotechnics, Delft, the Netherlands

In this paper the authors use a composition of some simple systems to predict the vibration transfer between two foundations.

Both foundations are modelled by damped single-degree-of-freedom-systems, the energy transfer between the foundations by a transfer matrix. The parameters of the sub-soil are estimated by in-situ harmonic vibration experiments. For the single-degree-of-freedom-systems the coefficients are calculated from the response, the transfer matrices are based on the attenuation curves.

An interesting extension is the possibility to take a layering of the soil into account. Unfortunately, the authors do not explain this in detail, neither discuss the influence of e.g. a reflecting layer in the soil.

The predictions are compared with in-situ measurements after completing the structures. The predicted and measured power spectrum densities do fit well. Using the dynamic model built and a statistical model, the authors predict the probability of exceeding certain vibration limits. This leads to the possibility to take into account a number of vibration sources adaquately.

DISCUSSION ON

"PREDICTION OF VIBRATIONS OF FOOTINGS FOR HIGHLY SENSITIVE DEVICES"

BY WERNER PALLOKS, STEPHAN ACHILLES AND WERNER HIEDRICH

PAPER NO. 11.11

BY LARRY P. JEDELE, SENIOR PROJECT CONSULTANT SOIL AND MATERIALS ENGINEERS, INC. LIVONIA, MICHIGAN

The authors present an approach for evaluating the vibrations at proposed locations of vibration-sensitive devices either within existing or new facilities. Based on their experience, in some cases, maximum permissible vibration displacements of 1 μm are specified by the manufacturer. In my experience, certain equipment or operations require lower specified vibration levels. For these cases, it is essential to assess the ambient vibrations generated from existing sources within the facility such as other equipment or external sources such as traffic, etc. In addition, if new vibration-generating equipment is to be installed in the facility, its effects should also be considered.

For the investigation, the authors indicated the following steps are required:

1. perform field tests to determine dynamic soil properties at the site. This involves placing a mechanical vibrator on a test footing in the location of the new foundation. The dynamic response of the footing is determined over a range of frequencies;

2. perform soil attenuation tests at the ground surface concurrently with the test footing excitation test to determine the decay of vibration amplitude with increasing distance from the vibration source;

3. measure ambient vibrations generated from outside sources (traffic, etc.) at the location of the vibration-sensitive equipment;

4. calculate vibration at the location of the vibration-sensitive equipment from vibration-generating equipment in the plant;

5. calculate the transfer functions on the basis of distance from the vibration source and frequency; and

6. calculate the combined effect of all vibration sources on the new installation.

On this basis, the location of the new installation can be determined from minimum distances from each vibration source.

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Discussion on "Prediction of Vibrations of Footings for Highly Sensitive Devices" By Werner Palloks, Stephan Achilles, and Werner Heidrich (Paper No. 11.11)

by Mark Svinkin, Kilroy Structural Steel Co.
Cleveland, Ohio

The above paper shows a procedure for evaluation of anticipated vibrations at the planned locations for sensitive devices. It is considered different shapes of foundation vibrations using the half-space theory with experimental investigations of model parameters. Authors describe the loading conditions of the test footing and show footing dynamic responses. Actually those responses are experimental transfer functions of the footing-soil system. Received curves confirm the known fact that it is difficult to build complete transfer functions of foundations for a wide frequency range using a mechanical vibrator. The choice of the way for processing of the experimental data is very important. Unfortunately, there is no explanation given about it.

Problem on determining of the transfer functions for footing with passive excitation from soil vibrations is considered separately but very briefly. The valid assumptions determine soil conditions and footing dimensions for which present study can be applied. The transfer functions are calculated with complex transfer matrices on the basic concept of soil as the half-space. Those functions are product of some matrices. Certain parameters are taken from experimental data, other from calculation with boundary conditions, but it is not clear which should be calculated. Calculation of the transfer functions for footings under sensitive devices is a large and interesting question, and it is desirable it would be elaborated.

Soil vibrations caused by traffic are considered as stochastic process. It is obviously this approach is most suitable for those vibrations but probable requirements for permissible vibration levels of footing under sensitive devices are often unknown.

Application of the suggested procedure results in a comparison of calculated and measured transfer functions for test footing. These curves have good quality coincidence. Also shown the result of predicting save distances for production foundation under sensitive equipment from vibration sources. However, computed safe distances were not verified after the erection of that foundation.

Authors have carried out huge and interesting job for a solution of a serious problem. Unfortunately, it is difficult to pass judgement about possibilities, advantages or disadvantages of the suggested procedure because information in the paper is not enough. I guess the authors are going to continue their investigations and I would like to wish them success.

Discussion on "Simple Design Methods for Vibration Isolation by Wave Barriers" By Tahmeed M. Al-Hussaini and Shahid Ahmad (Paper No.11.12)

by Mark Svinkin, Kilroy Structural Steel Co.
Cleveland, Ohio.

This paper describes investigations of screening of ground oscillations by rectangular trenches in homogeneous soil deposits. Authors present simple formulas for computing the average amplitude reduction ratio in the area behind the trench. The depth and width of the trench, and distance after the trench are normalized with respect to the Rayleigh wavelength. Utilization of the dimensionless parameters have given the possibility of identical approach for different computing cases and generalization of obtained results. The effect of trench parameters on ground vibrations was conducted using a direct boundary element method algorithm. It is shown that for the same trench dimensions an open trench is always more effective than an infilled trench for screening of vertical vibrations. The normalized depth D is the primary factor which govers the screening efficiency of an open trench. For infilled trench optimum value D=1.2. In this case the screening effect also depends on the shear wave velocity ratio of the trench material to the soil, density ratio and the trench area. The influence of the last one is highly significant. It is seen that increase trench cross-section in 6.7 times allow to decrease ground vibrations in 4 times. The relative effect of velocity ratio for values more than 2.5 and density ratio on ground oscillations does not depend on trench cross-sections (Fig.6 and Fig.7), but for some reason the authors did not pay attention to this fact.

Important result described in this paper is the evaluation of the effect of layered soil on screening of ground vibrations by open trenches. It is shown when effect of layering should be taken into consideration.

The use of concrete infilled trenches for screening horizontal ground oscillations have been studied. Average amplitude reduction ratio depends on similar factors, same as the one for vertical ground vibrations except shape factor. Wave barriers is more effective in reducing of vertical vibrations than of horizontal vibrations.

Results computed by the suggested formulas have acceptable coincidence with those derived by rigorous numerical methods but a comparison with experimental data is not clear. Simple design expressions are the same for any distance from a wave source. It is not always to be well founded. Moreover, it is necessary for practical purposes the dependance of amplitudes of ground oscillations versus a distance from wave barrier because sometimes the effect of reducing of those amplitudes disappears at some places behind the screen.

The authors have carried out a large job for study the effect of trench parameters on ground vibrations after trenches. Received conclusions can be used to asses approximately the expediency of wave barrier application and the choice of screening structures.

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Discussion on
"Control of Seismic Response of Structures"
by
Chris P.Pantelides
(Paper No. 11.13)

by Mark Svinkin, Kilroy Structural Steel Co.
Cleveland, Ohio

This paper presents an interesting approach for decrease of seismic response of structures. It is discussed the concept of active control and techniques of it implementation for reduction the dynamic response of machine foundations. The basic components of an active control system are the sensor, taking an initial vibration signal and passing it to a computer, the computer, realizing an algorithm, and the control device, taking a signal from the computer and exerting the control force. An initial signal is either the deflection of structure or the magnitude of force. It is possible to measure both of them. There are three technical realizations of the discussed idea: active tendor system, active mass damper, and active base control mechanisms. Those techniques have different electro-mechanical systems. It would be desirable to know merits and demerits each of the technical realizations, which of them has preference, and, in particular, working frequency ranges. This information is not in the paper.

Author shows application of active tendor system on a simplified single-degree-of-freedom model. Only lateral stiffness of individual transverse concrete frames were employed in the analysis. For real machine foundations ground stiffness is much less than the one of concrete frames. This circumstance was not taken into account. The weighing matrices Q and R are chosen by the designer. May be it makes sense to think about elaboration of the optimal choice of those matrices and then designer's work would become more reliable.

Some remarks do not bring down implemented work. This and similar papers indicate the beginning of a new turn of mind - automatic regulation of vibrations of foundations under machines and equipment. It is obviously, that the concept of active control will be more developed in future.

Analysis of Damping in Soils as Applied to Machine Foundations by B.M. Basavanna and M.S. Nagakumar, Paper no. 11.16

Discussed by Paul Hölscher, Project enginee_, Delft Geotechnics, Delft, the Netherlands

The authors pose a mathematical question which is related to a practical ISO-norm (IS 5249). Using data from field-experiments, they show that the ascending part of the response of vertical vibration cannot always be used to estimate the viscous damping of the viscously damped single-degree-of-freedom-system. This question is clearly defined. It is a question of high interest for soil engineers, who follow the ISO-norm.

The authors present a possible solution of the problem. They suggest that the damping of the single-degree-of-freedom-system depends linearly on frequency. Using this assumption, they present new calculation results in clear tables. Indeed, the results are better.

This paper shows that the ISO-norm may give erroneous results, when the ascending part of the vertical vibration response is used. Unfortunately no information about the soil conditions is presented. Therefore, the paper should be seen as a warning for the engineer. A more thoroughfull study is needed in order to find out in which soil conditions these conclusions do hold generally.

DISCUSSION ON
CURRENT TRENDS IN DESIGN AND ANALYSIS
OF PAPER MACHINE FOUNDATIONS
BY
ALEX SY AND W.E. MCKEVITH
(PAPER NO.11.18)

BY P. SRINIVASULU, SENIOR SCIENTIST
STRUCTURAL ENGINEERING RESEARCH CENTRE,
MADRAS, INDIA.

The authors should be congratulated for the informative review of the recent trends in the analysis of paper machine foundations considering the interactions between machine frame, the concrete foundation, and the sub-structure consisting of soil or piles. The notable feature of the paper is the emphasis laid on forced vibration testing of such foundations with a view to collaborate the computer models. A passing reference was made to the care required to model the inter-face between the machine frame and concrete foundation. This is not however adequately illustrated. The uncertainties of the mathe-matical model lies in this as well as in the choice of stiffness and damping of the sub-structure elements. The two case histories cited seem to emphasise the stiffness parameter as the only adjustable variable to calibrate the analytical model. This is a point for debate.

It may also be mentioned that commercial programmes are available to handle complex eigen value problems. But they are seldom needed in normal practice.

The authors may like to clarify why the swept sine testing was adopted in the forced vibration testing methods in preference to the more easy steady state excitation at varying frequencies to spot the resonances of the actual foundations. The latter allows larger forces to be generated as needed in full scale testing and mechanical shakers with less cumbersom and more rugged field oriented equipment are now available for such a purpose.

Discussion on
"Control of Seismic Response of Structures"
by
Chris P.Pantelides
(Paper No. 11.13)

by Mark Svinkin, Kilroy Structural Steel Co.
Cleveland, Ohio

This paper presents an interesting approach for decrease of seismic response of structures. It is discussed the concept of active control and techniques of it implementation for reduction the dynamic response of machine foundations. The basic components of an active control system are the sensor, taking an initial vibration signal and passing it to a computer, the computer, realizing an algorithm, and the control device, taking a signal from the computer and exerting the control force. An initial signal is either the deflection of structure or the magnitude of force. It is possible to measure both of them. There are three technical realizations of the discussed idea: active tendor system, active mass damper, and active base control mechanisms. Those techniques have different electro-mechanical systems. It would be desirable to know merits and demerits each of the technical realizations, which of them has preference, and, in particular, working frequency ranges. This information is not in the paper.

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DISCUSSION ON

"CURRENT TRENDS IN DESIGN AND ANALYSIS OF PAPER MACHINE FOUNDATIONS"

BY ALEX SY AND W.E. McKEVITT

PAPER NO. 11.18

**BY LARRY P. JEDELE, SENIOR PROJECT CONSULTANT
SOIL AND MATERIALS ENGINEERS, INC.
LIVONIA, MICHIGAN**

The design and analysis of paper machine foundations has been affected in recent years due to changes in the framing structure of the paper machines themselves in addition to the demand to produce more paper of higher quality. Formerly, the older paper machines incorporated a very conservative design wherein the wrought iron frames were inherently rigid and were operated at slower speeds. These rigid machines were then placed on a monolithic concrete foundation. However, the newer paper machines are more flexible because of welded steel frame construction and are wider. Furthermore, the higher production speeds and demand for higher quality paper result in more stringent alignment and vibration tolerances while increasing the dynamic loads imposed on the machine. These machines are supported on raft foundations (with or without deep piles) or spread footings along with a space frame.

The authors present an analytical method to address these design problems which considers the complete system including machine-foundation-soil interaction. The two primary design aspects include resonance and meeting the manufacturer's permissible amplitudes of motion at the operating frequencies. The dynamic response analysis requires the determination of the stiffness and damping characteristics of each element of the model (soil, foundation and machine) and the magnitude and nature of the dynamic loads imposed.

Two case histories are presented in which the dynamic response is evaluated for each. For Case History No. 1, field tests were conducted by mounting a mechanical shaker unit on the partially constructed foundation and comparing the measured resonant frequencies with the natural frequencies determined from the computer analysis. The stiffness of the supporting soil was adjusted until these frequencies were essentially similar.

For Case History No. 2, a new section of the paper machine was to be replaced with a new one which was to be mounted on the existing foundation. To avoid a prolonged stoppage of the production operation, the mechanical shaker was mounted at various locations on the foundation and response tests were performed during brief periods to determine the resonant frequencies. Computed mode shapes with corresponding frequencies are also presented.

DISCUSSION ON DYNAMIC CONSIDERATIONS IN THE DESIGN OF PAPER MACHINE FOUNDATIONS BY J.P. LEEL (PAPER NO.11.20)

BY P. SRINIVASULU, SENIOR SCIENTIST
STRUCTURAL ENGINEERING RESEARCH CENTRE.
MADRAS, INDIA.

The paper, though very general, touches upon some important considerations in the design of paper machine foundations such as dynamic soil-structure interaction. The points raised are generally common to paper No.11.18 on the same subject. It is hard to appreciate the relevance of the elaborate computer model of the machine (as shown in Fig.3) coupled to a relatively stiff concrete frame and the soil springs below. It would have been more appropriate to cite typical results of one such practical analysis with and without consideration of the interactions involved.

Further it is hard to blieve that the damping in such a flexible machine system is contributed only by the soil below the foundation. Instead it may be generated more from within the machine and its numerous moving parts. The order of the dynamic forces generated in the machine which is not specified in the paper may not be high. But the expected tolerances being low for such machines, it may not be conservative to assume high damping from soils in the analysis of such systems.

The use of single degree freedom expression governed by eq.(1) is not justified in dynamic analysis especially when an elaborate computer model shown in Fig.3 is used.

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Discussion on
"Dynamic Characteristics of Crusher Supporting Structures"
by
P. Srinivasulu, N. Lakshmanan, and B. Sivarama Sarma
(Paper No. 11.21)

by Mark Svinkin, Kilroy Structural Steel Co.
Cleveland, Ohio

The present paper discusses the mechanical and structural problems involved in ensuring reliability and durability of crusher supporting structures in coal handling plants. Supporting structures are considered for ring granulators which are a recent development in hammer type crushers and widely applicable in coal plants.

The paper describes the nature of exciting dynamic forces transferred from such machines to their foundations. Ring granulator type crushers have nominally balanced but actually unbalanced rotating parts. Unbalance in the rotor is increased by gradual wear and tear of hammers and it may result in to breaking of the hammers. Also it is possible sudden hammer breaking when uncrushed bodies like, a shovel tooth or a boulder find themselves inside of the machines. Another cause for appearance of strong dynamic forces is "ceasing of crusher bearings", but this is an emergency situation. Shock forces induced by the impact action of the hammers are transferred on supporting structure as well.

On the basis of the review of codal provisions the authors suggested "a safe approach to account for 'a two hammer loss' from the outer most suspension as a case of abnormal condition for which the strength criterion should be satisfied by the foundation design." However, information on the most expected dynamic forces is not available. Also that worse case does not consider in the connection with a sudden stoppage of the crusher when high vibrations lead to severe damage of the machine and its supporting structures.

Authors have carried out unique experiments. The operative ring granulator type crusher was erected on a reinforced concrete slab above 12 m high steel frame structure. This machine was exerted to the largest dynamic forces - repeated breakage of hammers and imitation the ingress of steel shovel pieces into the crasher chamber. Unfortunately, the description of those experiments was done extremely briefly. There are only notes on "dynamic computations for the two hammer breaking condition showed that the induced stresses in many members of the steel structure exceeded the yield stresses." Interesting results have showed with more details in investigation of the transient stage in the machine which was coasted down from the operating speed. For that process maximum horizontal amplitude was obtained as 1000 microns. Such a vibration amplitude of steel frame at height of 12 m can not cause dangerous stresses in steel structures, but observation of those vibrations is not a pleasant sight. Doubts expressed in the paper about high fatigue stresses can be verified by a computation or by a test.

Vibration isolation of a crusher-motor assembly was employed for decrease of foundation vibrations. In vain steel structure vibrations have not been shown after use of vibroisolation. A comparison of them with steel structure vibrations for regular mounting of a machine is always striking. Also the paper discribes investigations with a reinforced concrete foundation for multiple crushers. In that case vibration isolation could be used as well. A crusher-motor assembly may be installed on a common steel frame without concrete slab. It is possible to use another way when a motor remains on the foundation and the crusher is joined with the motor by flexible coupling.

Structure vibrations excited by vibrating screens could be attempted to reduce. In particular, utilization of unloaded beams, which are computed only for the strength, somewhat decrease dynamic forces on supporting structures.

The authors have made a good work, but the best way does not used for its presentation. Obtained data will be undoubtedly applied in design practice. Results of investigation have emphasized the necessity of crusher mounting on the vibration isolation that gives the possibility of junction of crusher supporting structures with building structures. This fact is very useful for technological changes in coal handling plants.

DISCUSSION ON
INTEGRATED ANALYSIS OF TURBO MACHINERY FRAME-FOUNDATION-SOIL INTERACTION
BY
MADHIRA, R. MADHAV, N.G.R. IYENGAR AND S. KATHIROLI
(PAPER NO. 11.23)

BY P. SRINIVASULU, SENIOR SCIENTIST
STRUCTURAL ENGINEERING RESEARCH CENTRE, MADRAS, INDIA.

The authors have rightly emphasised the need for an integrated approach for the analysis of the rotor-foundation-soil system considering their mutual interactions on the dynamic behaviour of the composite group. The literature review is however seen to be limited to the influence of soil-structure interaction and no work on machine-structure interaction has been touched, although the title of the paper includes all the three major constituents - the machine, the structure and the soil.

The theory involved in frequency domain method of solution has been dealt with in an elaborate detail (than what is perhaps needed in a paper like this) starting from the classical derivation of the matrix equation of motion leading to their end solu-tion. Instead, the authors could have descsribed in more detail their idealised model, especially the semi-infinite soil medium justifying the assumptions wherever made.

In dealing with the elements, lumped mass idealisation has been adopted with some justification, which is not convincing. The geometry of a turbo-genereator foundation (which the authors have analysed) as normally adopted in practice is such that the influence of continuous mass distribution over the elements, the influence of shear and rotary inertia cannot normally be overlooked.

The details of the modified influence boundary condition method adopted by the authors could have been explained in the text. The symmetry of soil-mat system about the axes assumed here does not normally exist in practical foundations of this type.

Blocks I & II mentioned in the text under step by step procedure do not seem to have been marked in the figures.

Frequency axis in Fig.4 does not show units. Is it in Hz or sec^{-1}? This omission makes it difficult to appreciate the inferences drawn on the influence of frequency. The basis for the chosen values of frequency dependant stiffness of damping values of the fluid bearings or its reference source could have been explained. On the whole, the data adopted in Table-1 seems to consist of assumed values. If the data however represents any practical problem, the power output in units of MW of the machinery in question if mentioned, would be useful for readers to draw broad inferences on the influence of parameters studied.

Although one can appreciate the utility in using the mat impedance matrix to replace the entire base structure and supporting soil, one fails to appreciate the general conclusions drawn in the paper under the four cases studied and their prectical relevance for the benefit of designers of such structural systems.

The paper on the whole, forms a good analytical exercise for the analysis of a complex system involving more than one discipline. The effort is commendable and the authors should be congratulated for the work presented.

Discussion by T.S. Thandavamoorthy, Assistant Director, Structural Engineering Research Centre, Madras, on "Response of Frame Foundations to Vertical Vibrations" by P.J. Moore and T.P. Tan of University of Melbourne, Australia

Paper No.11.24

Our appreciation to the authors for presenting experimental results of vertical vibration of small steel portal frames of different stiffnesses subjected to dynamic loads at the centre of the frame. The authors have attempted by their study to give an improved understanding of the dynamic behaviour of relatively slender frames in contrast to the traditional frames made of massive concrete frames.

In a practical situation, a framed foundation for a turbo generator is of spatial geometry. The interaction of the longitudinal frame with the cross frame is also important. A study conducted by Srinivasulu et.al (1977) considering the framed structure as a three-dimensional space frame has revealed that the natural frequencies were from 3 Hz to 1000 Hz. Many frequencies were very close to the operating speed. But, the computed amplitudes were very low. This was also validated by taking measurements on existing concrete T.G. foundation. Both recorded and computed amplitudes were far below the permissible levels indicating the possibility of over conservative design of members. A similar study on a three-dimensional steel frame would be worth attempting and it may also be helpful to formulate design guidelines for an economical foundation.

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(PAPER NO. 11.23)

BY P. SRINIVASULU, SENIOR SCIENTIST
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DISCUSSION ON
RESPONSE OF FRAME FOUNDATIONS TO VERTICAL VIBRATIONS
BY
P.J. MOORE AND T.P. TAN
(PAPER NO. 11.24)

BY P. SRINIVASULU, SENIOR SCIENTIST
STRUCTURAL ENGINEERING RESEARCH CENTRE, MADRAS, INDIA.

The authors have compared the measured frequencies and amplitude response of a single bay frame with those yielded by the so called "combined method" and the "dynamic deformation method". It is not clear whether all the five frames, whose sectional properties are given in Table-2 represent any practical framed type foundation or they are hypothetical examples. In the latter case, the inferences drawn from the paper may not benefit a practical designer of such foundations. Following observations are worth mentioning from the text of the paper.

1. The matrix A given in eq.(6) may be more appropriately called dynamical matrix which is equal to K M where K is the stiffness and M is the mass matrix.

2. The value of C_2 (vide eq.5) for the computed sand bed used in the illustrative model is not mentioned nor the method of its experimental evaluation explained.

3. The "combined method" of calculation presupposes a rigid beam and relatively slender columns. The use of root formula given by eq.(1) is known to be good enough for practical applications and is widely adopted in design offices for the design of framed foundations for turbo-machines. Adequate evidence is not seen in the paper for the unfavourable prediction of frequencies by the combined method.

4. In the last para in p 1545, it is stated that the "first four natural frequencies for a three degree of freedom analysis" are identified. It is not clear how there could be "four" natural frequencies for a "three degree system".

5. One could expect an asymptotic trend in resonant frequencies as the frame stiffness is increased many fold compared to the subgrade stiffness. The frame behaviour then tends to that of a rigid frame resting on elastic bed. This evidence is however not seen within the range of stiffnesses studied by the authors.

DISCUSSION ON
TURBO GENERATOR FOUNDATION ANALYSIS UNDER WIDE RANGE (SEISMIC IN PARTICULAR) EXCITATION
BY
PROF. IGOR ANDRIANOV AND
PROF. VLADEMIR SEDIN
(PAPER NO. 11.30)

BY P. SRINIVASULU, SENIOR SCIENTIST
STRUCTURAL ENGINEERING RESEARCH CENTRE, MADRAS, INDIA.

The paper deals with an analytical treatment to the vibration problem of the base plate of a turbo generator foundation. In the absence of an illustrating figure showing the structural configuration being analysed, it is difficult to appreciate the specified boundary conditions at the edges of the base plate as defined by eq.(2). It is not clear what the authors refer to as "wall" whose modulus of elasticity is given as E1. The title of the paper refers to the turbo-generator analysis under wide range seismic excitation. Without considering super structure part above the base plate of such a foundation, the content of the paper does not seem to justify the title as given. The paper appears too brief for the involved theoretical content to justify its application to the practical foundations of this type which is mentioned in the title.

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RESPONSE OF FRAME FOUNDATIONS TO VERTICAL VIBRATIONS
BY
P.J. MOORE AND T.P. TAN
(PAPER NO. 11.24)

BY P. SRINIVASULU, SENIOR SCIENTIST
STRUCTURAL ENGINEERING RESEARCH CENTRE, MADRAS, INDIA.

The authors have compared the measured frequencies and amplitude response of a single bay frame with those yielded by the so called "combined method" and the "dynamic deformation method". It is not clear whether all the five frames, whose sectional properties are given in Table-2 represent any practical framed type foundation or they are hypothetical examples. In the latter case, the inferences drawn from the paper may not benefit a practical designer of such foundations. Following observations are worth mentioning from the text of the paper.

1. The matrix A given in eq.(6) may be more appropriately called dynamical matrix which is equal to K M where K is the stiffness and M is the mass matrix.

2. The value of C_2 (vide eq.5) for the computed sand bed used in the illustrative model is not mentioned nor the method of its experimental evaluation explained.

3. The "combined method" of calculation presupposes a rigid beam and relatively slender columns. The use of root formula given by eq.(1) is known to be good enough for practical applications and is widely adopted in design offices for the design of framed foundations for turbo-machines. Adequate evidence is not seen in the paper for the unfavourable prediction of frequencies by the combined method.

4. In the last para in p 1545, it is stated that the "first four natural frequencies for a three degree of freedom analysis" are identified. It is not clear how there could be "four" natural frequencies for a "three degree system".

5. One could expect an asymptotic trend in resonant frequencies as the frame stiffness is increased many fold compared to the subgrade stiffness. The frame behaviour then tends to that of a rigid frame resting on elastic bed. This evidence is however not seen within the range of stiffnesses studied by the authors.

DISCUSSION ON
TURBO GENERATOR FOUNDATION ANALYSIS UNDER WIDE RANGE (SEISMIC IN PARTICULAR) EXCITATION
BY
PROF. IGOR ANDRIANOV AND
PROF. VLADEMIR SEDIN
(PAPER NO. 11.30)

BY P. SRINIVASULU, SENIOR SCIENTIST
STRUCTURAL ENGINEERING RESEARCH CENTRE, MADRAS, INDIA.

The paper deals with an analytical treatment to the vibration problem of the base plate of a turbo generator foundation. In the absence of an illustrating figure showing the structural configuration being analysed, it is difficult to appreciate the specified boundary conditions at the edges of the base plate as defined by eq.(2). It is not clear what the authors refer to as "wall" whose modulus of elasticity is given as E1. The title of the paper refers to the turbo-generator analysis under wide range seismic excitation. Without considering super structure part above the base plate of such a foundation, the content of the paper does not seem to justify the title as given. The paper appears too brief for the involved theoretical content to justify its application to the practical foundations of this type which is mentioned in the title.

Discussion by T.S. Thandavamoorthy, Assistant Director, Structural Engineering Research Centre, Madras, on "Turbogenerator Foundation Analysis under Wide-range (Seismic in particular) Excitation" by Igor Andrianov and Vladimir Sedin of Institute of Civil Engineering, Dniepropetrovsk, USSR

Paper No.11.30

The authors have presented quite an interesting theoretical study on the dynamics of a ribbed foundation plate modelled as a Winkler foundation.

Barkan (1962) has observed that the lower slab of foundation under turbogenerator is not subjected to vibration under machine induced dynamic loads. This has also been confirmed by Srinivasulu et al (1977). In the light of these observations, the influence of the dynamic deflection of the supporting base plate due to base excitation on the vibration of the turbogenerator foundation assumes greater importance in the design of T.G. foundation in seismic regions. These research findings will be quite useful in such situations.

References

Barkan, D.D. (1962), "Dynamics of bases and foundations", McGraw-Hill Book Company, Inc., New York.

Srinivasulu, P., Lakshmanan, N., and Thandavamoorthy, T.S. (1977), "Dynamic analysis of framed foundations for rotating machinery", Journal of Structural Engineering, Vol.4, No.4, January, pp.177-181.

Ground Vibration Isolated by Silo and Pile Barriers by Yang Xian-Jian, paper no. 11.32
Discussed by Paul Hölscher, Project engineer, Delft Geotechnics, Delft, the Netherlands

In order to find out the effect of ground vibration isolation the author clearly distinquishes three mechanisms: transmission, diffraction and coincidence (due to resonance phenomena). For each mechanism he presents some formulae to estimate the effectiveness of vibration isolation. These formulae results in design rules for such structures.

Unfortunately the mathematics is shorthand and sometimes confusing. Therefore the background of the proposed design rules is not clear and this may hinder the application of such rules.

The examples show that a reasonable decrease of vibration is obtained, using the isolation designed according the proposed formulae. However, the value of the paper will increase strongly if the author shows that the design is improved by applying the design rules, explains why at certain points only a small decrease is observed and shows the contribution of each mechanism to the total isolation.

A Numerical Solution of Wave Equation for Dynamic Compaction of Soil by K.B. Agarwal and B. Siva Ram, paper no. 11.33
Discussed by Paul Hölscher, Project engineer, Delft Geotechnics, Delft, the Netherlands

The authors develop a finite difference scheme for dynamic loading at the surface in order to calculate the depth of compaction by explosives. The general question why the authors prefer the use of a finite difference scheme is not discussed. In general a finite difference scheme is more suitable to simulate high gradients, which appear during blasting, than the widely applied finite element method.

I do support their choice for a finite difference scheme, but I wonder whether no stronger finite difference scheme for the elastic wave-propagation problem is available. In textbooks about gas dynamics and numerical methods a large number of finite difference schemes has been developped [see e.g. Smith, Num. Sol. of Part. Diff. Eq., Fin. Diff. Meth., Oxford Appl. Math. Series, 3rd ed., 1985]. The authors do not compare the efficiency and accuracy of their scheme with known schemes.

In their plane strain scheme the influence of spherical radiation is ignored. In axial symmetry the energy radiates in more directions and consequently a lower depth of compaction will be obtained.

In general terms the presented method shows that a finite difference scheme together with a criterion for compaction gives a possibility to estimate the effectiveness of blasting compaction.

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Discussion by Dr. N. Lakshmanan, Assistant Director, Structural Engineering Research Centre, Madras, India, on "A Study of Blast Pressure from Underwater Borehole Blasting by T.S. Thandavamoorthy, Structural Engineering Research Centre, Madras, India

Paper No.11.35

The phenomenon of blast loading in any medium is complex and in majority of the cases the pressure-time history is obtained based on empirical relationships derived from experimental investigations. The author has presented the data of one such experimental programme wherein the pressure-time histories, response-spectra, and transfer functions due to underwater borehole blasting are derived at a specified location. It is very interesting to note that the peak pressures obtained are considerably less than those due to freely suspended charges underwater. This is as expected because considerable energy would be dissipated in the damage caused to the concrete slab around the borehole. It is probable that orientation or location of the hydrophone with respect to the borehole may considerably influence the blast parameters. Vertically above the borehole, the pressures that are built up may be considerably higher due to wave reflection from the concrete mat. Unlike the case of suspended charge, the problem is not axi-symmetric. The shape of the charge, either cylindrical or spherical, may also significantly influence the blast parameters that are of interest to a designer. The paper leads one to conclude that simulated blast tests alone can provide an answer for individual cases, as wave reflections from adjoining structures will also have substantial influence. The author is to be complimented for attempting experiments in a new area which has a lot of potential for further work. The data discussed clearly indicate that the stand-off distances from safety criteria will be substantially different in underwater borehole blasting as compared to freely suspended charges which again need further probing.

Author's Replies
"Predicting Vibrations of Soil and Buildings Excited by Machine Foundations Under Dynamic Loads"
By
Mark Svinkin
(Paper No.11.1)

1. The Addition to the General Report by Toyoaki Nogami Associate Head of Ocean Engineering Scripps Institution of Oceanography University of California

The method to predict the complete vibro-records of soil and structures can be used on shorter distances from designed machine foundations as well. The principle of superposition should be applied for those cases.

2. Reply to
Paul Hölscher
Project Engineer, Delft Geotechnics,
Delft, the Netherlands

The results of predicting soil oscillations for three sites have been illustrated in the paper. Expecting soil oscillations are shown for three typical vibration sources: a foundation with the foot area of 158 m^2 under a powerful drop hammer, a vibration isolation foundation with the outer foot area of 116 m^2 under a large drop hammer, and a testing foundation with $A=5.1$ m^2 under a mechanical vibrator with a harmonic exciting force.

It is not necessary to illustrate rest predicting soil motions because the study on 13 sites was analyzed and generalized.

3. Reply to
P. Srinivasulu
Senior Scientist, Structural Engineering Research Center
Madras, India

The coefficient of elastic uniform compression of soil C_Z was computed according to Specialty Building Code and Savinov's method. The last one is described in the Savinov's book "*Modern Design of Machine Foundations and Their Calculation*", Stroiizdat, Leningrad, 1979.

Modules of damping Φ is determined as follows:

$$\Phi=2\frac{c}{f_{nz}^2}$$

Where c - Damping constant
f_{nz} - Natural frequency of vertical vibrations of foundation

The paper contains information about the choice of values for modules of damping for predicting calculations of soil oscillations.

The seismograph VAGIK and an oscillograph with GB galvanometer is a vibration measurement system with the frequency range for displacements from 1 Hz to 100 Hz.

4. Replay to
T.S. Thandavamoorthy
Assistant Director, Structural Engineering Research Center,
Madras, India

I am grateful to the discusser that he shares my point of view about opportunities for applications of the suggested method.

A couple of words are connected with remarks. The dimensions of a field applying the dynamic load from the machine foundation to the base practically does not affect soil vibrations at the distance more than 10-30 meters from the foundation center of gravity. These results were elaborated at my paper "*The Effect of the Area of Machine Foundation Foot - Wave Source on Amplitudes of Soil Oscillations*" (in Russian), Foundations under Equipment, Proceedings of the Leningrad Design Institute for Industrial Construction, Leningrad, 1978, 25-32.

"erratum"

PAGE 1438. Second column, line 24 should read: by Specialty Building Code and Savinov's method (Savinov, 1979).

Authors reply on the discussion on
the discussion by: T.S. Thandavamoorthy, Structural Engineering Research Center, Madras, India
Paper 11.4 "Pile driving Analysis: Two-phase Finite Element Approach"
By: P. Hölscher, Delft Geotechnics, Delft, the Netherlands

The discusser suggests two usefull extensions (applications) of the presented study:

1 Taking into the effect of soil layering.
The finite element approach presented in the article, is indeed very suitable to investigate these effects. At layer separations the flow of pore water might be axially, and the effective stress (=strength) might show large changes. Such problems can be solved using the two-phase finite element approach, but this subject was behind the scope of the study.

2 Taking into account radial non-homogenity.
Linking the results of the study with studies with radially non-homogeneous soil (refered to by Thandavamoorthy) is an important, but difficult task. The importance is shown by the study: if volumetric changes occur, the influence of the shaft friction is not limited to the interface only. The difficulty is to find a suitable and realistic model of the material properties in the inhomogeneous region around the pile.
The value of both the presented study and the studies refered to by the discusser will increase if a mutual influence occurs.

References:

Sweet, J., Barends, F.B.J., Van Loon Engels, C. & Van der Kogel, H.; A method dynamic soil-structure interaction problems; Proc. Int. Conf. Num. Meth. for Non-linear Problems. eds. Taylor, C e.a., Swansea, 1980

Sweet, J; SATURN, a multi-dimensional two-phase computer program, which treats the non-linear behaviour of continua using the finite element

Closure to

"Torsional Dynamic Response of Embedded Footings", Paper No. 11.7

by Peiji Yu, IWHR, China, F.E. Richart, Jr., and E.B. Wylie, Univ.of Michigan, Ann Arbor, MI.

The program CHARFOUND presented in the paper is based on a characteristic-like method for solving the multidimensional axisymmetric torsional wave equations. The computational results from the program were compared with the published results for evaluating torsional dynamic response of embedded footings in an elastic half-space as shown in Figs. 5 and 6., and the agreements were good. Moreover, the program was used to analyze the static torsion of a rigid cylinder embedded in an elastic half-space and the results were compared with Luco's solution. Luco (1976) utilized the integral representations to reduce the problem to solution of two integral equations. Thus, his numerical results given in Table 1 should be considered as rigorous ones. The comparison plotted in Fig. 15 shows an exact agreement. It firmly supports the approach and the program CHARFOUND.

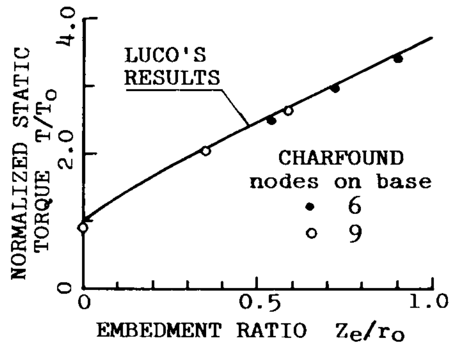

Fig. 15 Normalized Static Torque vs. Embedment Ratio

Three types of soil behavior have been considered for analyzing an embedded footing and the results were compared with the experimental results reported by Fry (1963). It was assumed for the nonlinear inelastic condition that the shearing stress-strain curves of soils followed the Ramberg-Osgood equations. The material damping was reflected by the hysteresis loop of shearing stress and strain as shown in Fig. 11-b. In the program CHARFOUND, slip along the interface of the footing and the medium could be considered on either the sideface or the base of the foot-ing or on both. However, when analyzing the special problem in the paper, slip was considered only along the sideface because the limiting slip stress was a function of the overburden pressure at each location. Thus, along this sideface these limiting shearing stresses were smaller than at the base. Also, the applied torque was not large enough to cause significant slip at the base.

In conclusion, all of the results presented by the writers and various authors, including Manyando (1990), showed that it is necessary to consider the soil nonlinearity when analyzing the torsional interaction between footings and soils. In design, slip at the base of the footing should be minimized, but even if this is accomplished, there is the possibility of slip occurring along the vertical sideface when the limiting shearing stress is a function of the overburden pressure. Slip along this sideface should be considered in the analysis, and slip at the base should be minimized during design.

Authors reply on the discussion on the discussion by: T.S. Thandavamoorthy, Structural Engineering Research Center, Madras, India
Paper 11.4 "Pile driving Analysis: Two-phase Finite Element Approach"
By: P. Hölscher, Delft Geotechnics, Delft, the Netherlands

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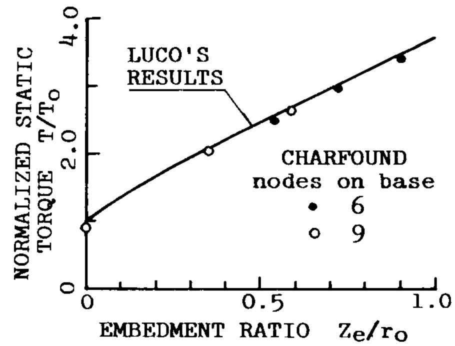

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AUTHOR'S RESPONSE TO QUESTIONS ON

"PILE DRIVING CRITERIA FOR CONSTRUCTION NEAR AN HISTORIC DAM"

BY L.P. JEDELE

PAPER NO. 11.8

During the discussion time for Session XI, several questions were posed to the author concerning soil conditions, construction details and analytical methods relating to the case history presented in the proceedings. The purpose of this discussion is to answer some of those questions.

The soil conditions at the site consisted of silty clays overlying sandy/silty clay till (hardpan) material. The overlying silty clays were generally stiff to very stiff, while the underlying hardpan soils generally are hard soils with moisture contents below 10 percent. Typically, these hardpan materials provide support for end-bearing drilled pier foundations. In the case of this project, the hardpan was used to develop skin friction along the effective perimeter of the H-piles which support the bridge abutment.

In general, some details concerning the simulated test pile and production piles should be noted. As indicated in the paper, the simulated test pile consisted of a 4-inch diameter closed end casing which was installed in a pre-drilled hole extending to the top of the hardpan. By contrast, the production piles consisted of H-pile sections, which were also installed in a pre-drilled hole extending to the top of the hardpan layer. The length of the pre-drilled holes for the test and production piles varied. The pre-drilled hole for the test pile was within 10 feet of the ground surface, while the ones for the production piles were on the order of 30 to 40 feet. The difference in the pilot hole length was due to the fill required to construct the bridge approach embankments on both sides of the river.

Furthermore, the driving details for both the test and production piles are of interest. Since the test pile was driven with a 300-pound weight dropped from heights of 5 and 10 feet, the low energy limited the penetration of the pile to just a few inches into the hardpan. The number of impacts on the test pile was limited because the purpose of the driving was to obtain enough vibration data for the analysis in developing the attenuation and scaled distance characteristics of the site. In contrast, the production piles were driven at least ten feet into the hardpan to develop the design load capacity. However, vibration measurements were obtained during the entire driving operation for the production piles until final set occurred.

Notwithstanding these differences between the test and production piles during driving, the vibration measurements indicated a remarkably good correlation when the data from each were compared on Figure 6 in the paper. This seems to indicate, for at least this project, that variations in pile type and driving length do not affect the vibration response.

Finally, a question was raised about the so-called scaled distance approach to analyzing vibration level, distance from the source of vibration and energy level of the vibration source. This approach was presented by Wiss (1981) where the following equation is used:

$$V = K\,(D/(E)^{1/2})^{-n}$$ where:

- V = peak particle velocity in inches per second
- K = intercept in inches per second (value of V at $D/E^{1/2} = 1$ $(ft/lb)^{1/2}$)
- D = distance in feet
- E = energy in foot-pounds
- n = slope or attenuation rate
- $D/E^{1/2}$ = scaled distance

The vibration data for this method of analysis is presented in graphical form on Figures 3 and 6 in the paper.

Reply to Discussion on Paper No. 11.12 "Simple Design Methods for Vibration Isolation by Wave Barriers" by Tahmeed M. Al-Hussaini, Shahid Ahmad

The authors are thankful to the discusser for his interest in the work and would like to take this opportunity to clarify certain points related to his comments.

The authors agree with the discusser that in Fig. 6, the variation of the amplitude reduction ratio with the shear wave velocity ratio at velocity ratios greater than 2.5 has a more or less similar slope for different barrier cross-sections. Similar is the case for density ratio in Fig. 7. However, the model $\overline{A}_{rv} = I_s I_v I_d I_a$ was developed in such a way that the velocity factor I_v and the density factor I_d are not functions of the velocity ratio or the density ratio alone. They are also functions of the barrier cross-sectional area.

In the paper, comparison was done with regard to the experimental results of Haupt (1978), who did not present the actual depth and widths of the concrete barriers. Hence, the depth to width ratio was assumed. The authors admit that a better comparison could have been done with the test data of Haupt (1981), where the actual dimensions of concrete barriers were given. Haupt (1978, 1981) found that his test results had reasonable agreement with results he obtained using a special plane-strain finite element analysis. The simple model which is also based on a plane-strain numerical study is, therefore, used to compare with Haupt's experimental data in the following table.

Table 1

Comparison of Simple Model with Haupt's (1981) Experimental Results

Test No.	*W*	*D*	*A*	V_{sb}/V_{ss}	ρ_b/ρ_s	$\overline{A}_{rv}$(Haupt)	$\overline{A}_{rv}$(Model)
M1/30	0.20	1.02	0.204	5.0	1.35	0.70	0.71
M2/30	0.39	0.98	0.382	5.0	1.35	0.47	0.50
M2/40	0.30	0.76	0.228	5.0	1.35	0.68	0.63
M3/30	1.00	0.40	0.400	5.0	1.35	0.60	0.72
M4/24	1.24	0.50	0.620	5.0	1.35	0.45	0.54
M5/24	0.26	1.28	0.333	8.0	1.35	0.41	0.56

The results of the simple model agree reasonably well with the experimental results.

The average amplitude reduction ratio $\overline{A}_{rv}$ is computed over an area extending to a distance of 10Lr (Lr=Rayleigh wave length) after the barrier. The ground displacement amplitudes after a distance of 10Lr from the barrier location is so small compared to those just after the barrier location (Fig.5; Ahmad and Al-Hussaini, 1991) that the crucial zone that needs screening lies within a distance of 10Lr after the barrier. The average amplitude reduction ratio based on a distance of 10Lr can also be safely used to represent other sizes of reduction zone extending to distances such as 2.5Lr, 5Lr or 7.5Lr after the barrier.

The effect of the distance of the barrier from the source has been studied (Fig. 6 ; Ahmad and Al-Hussaini, 1991), where the distance was varied from 3Lr to 12Lr. For both open and concrete barriers, the influence was found to be relatively small.

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Ahmad, S. and Al-Hussaini, T. M. 'Simplified design for vibration screening by open and infilled trenches', J. Geotech. Eng. Div., ASCE, 117(1), 1991, 67-88.

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Haupt, W. A. 'Model tests on screening of surface waves', Proc. Int. Conf. Soil Mech. Foun. Eng., 10th Stockholm, Vol. 3, 1981, 215-222.

RESPONSE TO DISCUSSION ON DYNAMIC CONSIDERATIONS IN THE DESIGN OF PAPER MACHINE FOUNDATIONS BY J. P. LEE (PAPER NO. 11.20)

DISCUSSION BY P. SRINIVASULU, SENIOR SCIENTIST STRUCTURAL ENGINEERING BRANCH CENTER MADRAS, INDIA.

I appreciate the comments made by Srinivasulu, that give me the opportunity to clarify and supplement some ambiguous points in my paper.

First of all, the inclusion of the concrete and the soil stiffnesses in the computer model is a very important factor in the calculation of the machine/foundation system frequency. For a press section Brown & Root recently analyzed, the natural frequency was about 12 Hz. when the paper machine was considered fixed at its base (machine frequency). However, the natural frequency of the machine system was reduced to about 6 Hz. when the concrete and the soil stiffnesses were included in the computer model (system frequency). It is noted that the extent of frequency reduction depends, among others, on the charateristics of the underlying soil.

The paper refers to a set of equations that can be used to calculate the damping coefficients for the soil springs. It does not mean or imply that the damping of the system is contributed only by the soil. When a model superposition technique is used, a damping value should be specified for each mode. As one may expect, if a particular mode shape indicates that the deformation of the model is essentially that from the soil, then the damping value close to that of the soil damping would be adequate to use. In general, the damping value for a mode should be carefully evaluated and is an important part of the response calculation.

Finally, the equation (1) in the paper was used to illustrate that if a resonant condition occurs, the dynamic amplification can be significant, especially when the damping value of the system is low. in our calculation of the press section, all translational degrees of freedom of joints that have nominal masses are retained. For this press section as shown in figure (3), a total of 64 degrees of freedom was used.

Reply to Discussion on Paper No. 11.12
"Simple Design Methods for Vibration Isolation by Wave Barriers" by Tahmeed M. Al-Hussaini, Shahid Ahmad

The authors are thankful to the discusser for his interest in the work and would like to take this opportunity to clarify certain points related to his comments.

The authors agree with the discusser that in Fig. 6, the variation of the amplitude reduction ratio with the shear wave velocity ratio at velocity ratios greater than 2.5 has a more or less similar slope for different barrier cross-sections. Similar is the case for density ratio in Fig. 7. However, the model $\overline{A}_{rv} = I_s I_v I_d I_a$ was developed in such a way that the velocity factor I_v and the density factor I_d are not functions of the velocity ratio or the density ratio alone. They are also functions of the barrier cross-sectional area.

In the paper, comparison was done with regard to the experimental results of Haupt (1978), who did not present the actual depth and widths of the concrete barriers. Hence, the depth to width ratio was assumed. The authors admit that a better comparison could have been done with the test data of Haupt (1981), where the actual dimensions of concrete barriers were given. Haupt (1978, 1981) found that his test results had reasonable agreement with results he obtained using a special plane-strain finite element analysis. The simple model which is also based on a plane-strain numerical study is, therefore, used to compare with Haupt's experimental data in the following table.

Table 1

Comparison of Simple Model with Haupt's (1981) Experimental Results

Test No.	W	D	A	V_{sB}/V_{ss}	ρ_B/ρ_s	$\overline{A}_{rv}$ (Haupt)	$\overline{A}_{rv}$ (Model)
M1/30	0.20	1.02	0.204	5.0	1.35	0.70	0.71
M2/30	0.39	0.98	0.382	5.0	1.35	0.47	0.50
M2/40	0.30	0.76	0.228	5.0	1.35	0.68	0.63
M3/30	1.00	0.40	0.400	5.0	1.35	0.60	0.72
M4/24	1.24	0.50	0.620	5.0	1.35	0.45	0.54
M5/24	0.26	1.28	0.333	8.0	1.35	0.41	0.56

The results of the simple model agree reasonably well with the experimental results.

The average amplitude reduction ratio $\overline{A}_{rv}$ is computed over an area extending to a distance of 10Lr (Lr=Rayleigh wave length) after the barrier. The ground displacement amplitudes after a distance of 10Lr from the barrier location is so small compared to those just after the barrier location (Fig.5; Ahmad and Al-Hussaini, 1991) that the crucial zone that needs screening lies within a distance of 10Lr after the barrier. The average amplitude reduction ratio based on a distance of 10Lr can also be safely used to represent other sizes of reduction zone extending to distances such as 2.5Lr, 5Lr or 7.5Lr after the barrier.

The effect of the distance of the barrier from the source has been studied (Fig. 6 ; Ahmad and Al-Hussaini, 1991), where the distance was varied from 3Lr to 12Lr. For both open and concrete barriers, the influence was found to be relatively small.

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Ahmad, S. and Al-Hussaini, T. M. 'Simplified design for vibration screening by open and infilled trenches', J. Geotech. Eng. Div., ASCE, 117(1), 1991, 67-88.

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RESPONSE TO DISCUSSION ON
DYNAMIC CONSIDERATIONS IN THE DESIGN OF PAPER MACHINE FOUNDATIONS
BY
J. P. LEE
(PAPER NO. 11.20)

DISCUSSION
BY P. SRINIVASULU, SENIOR SCIENTIST
STRUCTURAL ENGINEERING BRANCH CENTER
MADRAS, INDIA.

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Finally, the equation (1) in the paper was used to illustrate that if a resonant condition occurs, the dynamic amplification can be significant, especially when the damping value of the system is low. in our calculation of the press section, all translational degrees of freedom of joints that have nominal masses are retained. For this press section as shown in figure (3), a total of 64 degrees of freedom was used.

AUTHORS' REPLY

Discussion on
"Dynamic Characteristics of Crusher Supporting Structures"
by
P.Srinivasulu, N.Lakshmanan and B.Sivarama Sarma
(Paper No.11.21)

The authors are grateful to Mr.Mark Svinkin of M/s Kilroy Structural Steel Company, Cleveland, Ohio, for his excellent presentation of the summary of the paper and for his useful comments.

With regard to the steel structure supporting a crusher assembly at 12m height, a horizontal amplitude of 1000 microns under a "one hammer removal condition" was considered very severe for the machine as well as the supporting structure. Besides for the "two hammer removal condition", some members were seen by computation to experience stresses larger than the yield stress. That parts of the structure failed under fatigue was further verified subsequently by analysis based on the operational data collected from this installation (Srinivasulu and N.Lakshmanan - 1991). Although no measured data could be collected on the response of the structure after incorporating vibration isolation, subsequent reports from the site confirmed that the whole installation performed admirably well after this correction.

It was clearly stated in the paper that use of vibration isolation system was considered not feasible in the second case involving an RC foundation supporting six crushers, as it would have affected the head room needed for operations. The screens were already put out of operation and as such there was no occasion to look into the causes of vibrations originally attributed to screens. The dust resulting from the operation of crusher without segregation of the fines by the screens has resulted in the damage to the crusher itself and consequently to the supporting structure.The authors had limited the description of case studies to a brief narration of the problem reported in each case, the studies carried out and the end results obtained, leading to the final solutions adopted. This was intended to meet the objective of the paper presented in the particular technical session which is devoted to the theme "Dynamic characteristics of vibration sources other than earthquakes".

Reference:

Srinivasulu, P. and Lakshmanan, N. (1991), "Fatigue considerations in machine foundation design", Paper accepted for presentation at the International Symposium on Fatigue and Fracture Steel and Concrete Structures to be held at Madras, India, during December 1991.

Discussion on

Response of Frame Foundations to Vertical Vibrations

by

P.J. Moore and T.P. Tan
(Paper No. 11.24)

Response by Authors

The authors wish to express their thanks to those that took an interest in the paper by presenting a discussion and an attempt will be made to answer the questions that were raised. Regarding the matters raised by Srinivasulu :

a) The section properties listed in Table 2. are not hypothetical examples but represent the model frames that were tested under laboratory conditions.

b) The name given to matrix A in equation (6) is the same as that used by Kohoutek (1985) as referenced in the paper.

c) The values of C_Z (Barkan's coefficient of elastic uniform compression) are not listed for each test, nor are the values of many of the other parameters that appear in the equations. It was considered that a much longer paper would have been necessary to permit inclusion of all this information. The C_Z values were determined by means of cyclic plate load tests on footings of various diameters as originally described by Barkan (1962).

d) In applying the combined method of calculation it must be noted that the frames used in the tests were very flexible and the deflection due to bending was much greater than the other calculated deflections. The most rigid frame used was also quite flexible so that the trend towards behaviour of a rigid frame resting on an elastic bed could not be observed with the set of tests described in the paper.

e) The "three degree of freedom" system means that each node has two translational and one rotational degree of freedom. It does not follow that there are only three natural frequencies associated with the system. The lowest natural frequency could be looked upon as the fundamental frequency and the larger natural frequencies could be interpreted as higher harmonics.

The authors agree with Thandavamoorthy that it is essential to examine three dimensional space frames before a full understanding of behaviour can be obtained. However it was considered that there were still many uncertainties about the behaviour of two dimensional frames so that this appeared to the authors to be an obvious starting point.

Reply by the authors Prof. K.B. Agarwal and Dr. B. Siva Ram for the discussion on their paper No. 11.33 titled 'A numerical solution of wave equation for Dynamic Compaction of soil' at the 'Second International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics' St. Louis, Missouri (U.S.A) March 11-15, 1991.

The authors are very thankful to the discusser Er. Paul Holscher (Delft, Netherlands) for his interesting discussion. The discusser has rightly pointed out that the finite difference method which has been used in the paper is more correct and precise as compared to finite element method particularly for the compaction process using explosive material. The compaction was done using a foamed propellant and not directly an explosive material like dynamite. A foamed propellant is a mixture of high explosive and low explosive in hydrolysed protein base with a foaming agent. The influence of spherical radiation was not found to be significant and therefore has been ignored.

The other finite difference schemes were studied but the most suitable for the problem was picked up. The comparison has been made between the theoretical and actual depths of compaction at site and they seem to agree. In this paper no comparison has been put up with the other finite difference schemes but may be, shortly, we may send a paper.

Reply by T.S. Thandavamoorthy, author of the paper, "A Study of Blast Pressure from Underwater Borehole Blasting", to the discussion on it by Dr. N. Lakshmanan, Assistant Director, Structural Engineering Research Centre, Madras, India

Paper No.11.35

The author wishes to thank the discusser for expressing his compliments to the former and also for his fruitful discussions on the above paper.

It is very well known to the explosive and civil engineers engaged in blasting technique as applied to the civil engineering practice that the magnitude of the peak pressure is diminished substantially by the burial of the charge in a solid medium underwater. But, it was not estblished in quantitative terms by how much the magnitude of the peak pressure is reduced by burying the charge over that obtained from a freely suspended charge underwater. That way, this experiment was the first attempt to quantify the reduction in magnitude of the peak pressure.

The shape of the blast pressure obtained from a freely suspended charge underwater is fairly well established and also standardised which can be used for design purposes. The pressure-time history obtainable from a charge buried in a borehole underwater is relatively unknown and hence calls for an investigation to standardise the shape of such a blast pressure. The experiments were devised with the intention of standardising the blast pressure-time history, so that the same can be used to evaluate the response of the structures and also for design purposes.

It is a fact that the blast pressure attenuates with distance. There is no doubt that the magnitude of peak pressure is the highest over the charge. The distance selected in the experiment is based on the simulation of a full scale blasting operation at sea.

The shape of the charge is also an important parameter. The pressure-time histories of spherical and cylindrical waves are different. From the structural engineering point of view, the shock wave emanating from a buried charge and transmitted in a liquid medium impinges on the structure in the vicinity and thus causes vibration of the structure. So it becomes imperative to evaluate the response of the structure. This is a case where a structure is situated at a distance from the source of disturbance. Therefore, it does not really matter whether the problem is axi-symmetric or not.

Further research is needed before any concrete recommendation can be made on the standard shape for the blast pressure from underwater borehole blasting and on the safety criteria for the structures.