Obras y Proyectos
Revista de Ingeniería Civil

Accumulation of residual deformations due to cyclic loading with complicated strain loops

Fecha de entrega 30 de Septiembre 2008
Fecha de aceptación: 5 de Noviembre 2008
Pág. 43-48

Mauro Poblete[1,2] and Torsten Wichtmann[2]

[1]Institute of soil Mechanics and Rock Mechanics IBF, University Fridericiana of Karlsruhe, Engler-Bunte-Ring 14 D-76131, Karlsruhe, Germany, Engler-Bunte-Ring 14, D-76131, Karlsruhe, torsten.wichtman@ibf.uka.de
[2] Civil Engineering Departament, Catholic University of Concepción, mauro@ucsc.cl, Alonso de Rivera 2850, Concepción, Chile

Las fundaciones de estructuras próximas a líneas de ferrocarriles y las fundaciones de aerogeneradores tienen en común las cargas cíclicas a las cuales son sometidas durante periodos de tiempo prolongado. La acumulación deformaciones residuales se ha estudiado para casos prácticos como rellenos de estanques y silos y para el caso de fundaciones de máquinas donde los ciclos de deformación se presentan en una dimensión. Los terremotos y las olas y el viento provocan excitaciones irregulares, las cuales pueden inducir ciclos de deformación complicados sobras las estructuras. Este artículo presenta el proyecto propuesto para investigar numérica y experimentalmente la acumulación de deformaciones residuales en suelos granulares bajo cargas que inducen ciclos de deformación complicados. Se considera la realización de ensayos triaxiales cíclicos de larga duración en el nuevo laboratorio de dinámica de suelos del Instituto de Mecánica de Suelos y Rocas de la Universidad de Karlsruhe.

Palabras claves: modelo de acumulación de deformaciones, carga cíclica, suelo granular, deformaciones residuales, ciclos de deformación, ensayo triaxial dinámico

The foundations of structures near railways and the foundations of offshore wind turbines have in common the cyclic loading during a long period of time. The accumulation of residual deformations has been studied in the past for some practical problems such as filling of tanks and silos and for the case of machine foundations where the strain loops are approximately one-dimensional. In the case of earthquakes, wind and waves the excitations are not constant, leading to complicated strain loops. This paper presents a project proposal to investigate numerically and experimentally the accumulation of residual deformation in granular soils under loadings that generate complicated strain loops. The experimental approach considers long-time cyclic triaxial tests in the new Soil Dynamics Laboratory in the Institute of Soil Mechanics and Rock Mechanics in the Universität Karlsruhe.

Keywords: strain accumulation model, cyclic loading, granular soil, residual deformations, strain loops, dynamic triaxial test

DESCRIPTION OF THE PROBLEM

A cyclic loading leads to permanent deformations in the soil. As an example the accumulation of residual settlements of a shallow foundation due to cyclic loading is demonstrated schematically in Figure 1, where *t* is the time, *s* is the settlement of the footing, σ^{av} is the average stress applied to the foundation and σ^{ampl} is the stress amplitude.

In homogeneities in the soil or a different loading of neighboured foundations may lead to differential settlements, which may endanger the serviceability of a structure or even cause damage instatically indeterminated buildings.

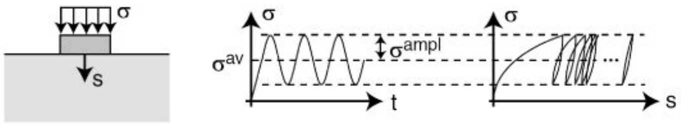


Figure 1: Settlements of a foundation due to cyclic loading, where t is the time, σ is a cyclic stress, σ^{av} is an average stress and σ^{ampl} is the stress amplitude

An example for excessive and irregular settlements is shown in Figures 2 and 3 (Heller, 1981). It is a brickwork wall of a hall for "S-Bahn" trains located in Berlin, Germany. An "S-Bahn" train station is located beside the hall. The trains caused a repeated loading of the subsoil.

During only eight years of operation, settlements of up to 80 mm accumulated. These settlements were unevenly distributed along the length of the hall causing large damage of the wall. Parts of the hall had to be demolished and reconstructed.

It is desirable to estimate the residual deformations due to cyclic loading already in the design phase of a building, for example by means of calculations using the Finite Element Method (FEM). If the number of cycles is high, "pure implicit" calculations (as shown in Figure 4a) using conventional $\dot{\sigma}$-$\dot{\varepsilon}$- constitutive models (e.g. hypoplasticity with intergranular strain (Niemunis and Herbe, 1997; von Wolffersdorff, 1996) or elastoplastic multi-surface models, where $\dot{\sigma}$ is the rate of effective stress, and $\dot{\varepsilon}$ is the rate of strain are not suitable due to the accumulation of numerical errors with each calculated increment and due to the huge claculation effort (Niemunis, 2000). Combined "implicit" and "explicit" (*N*-type) calculation strategies (as shown in Figure 4b) are indispensable. Only a few cycles are calculated implicitly with strain increments.

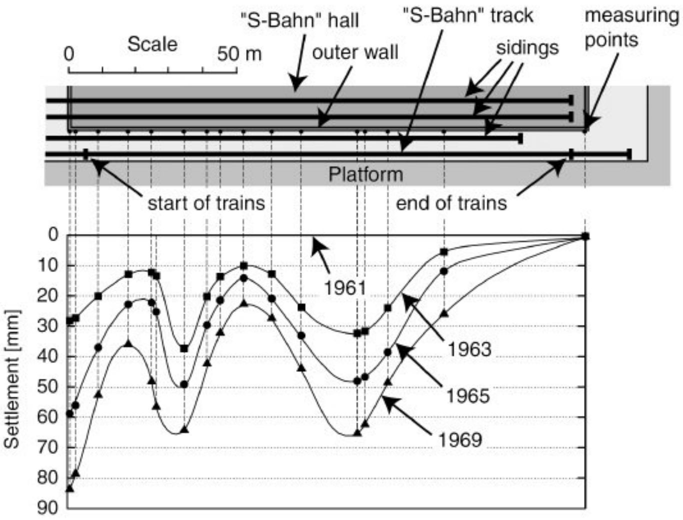


Figure 3. Measurements of settlement after Heller (1981)

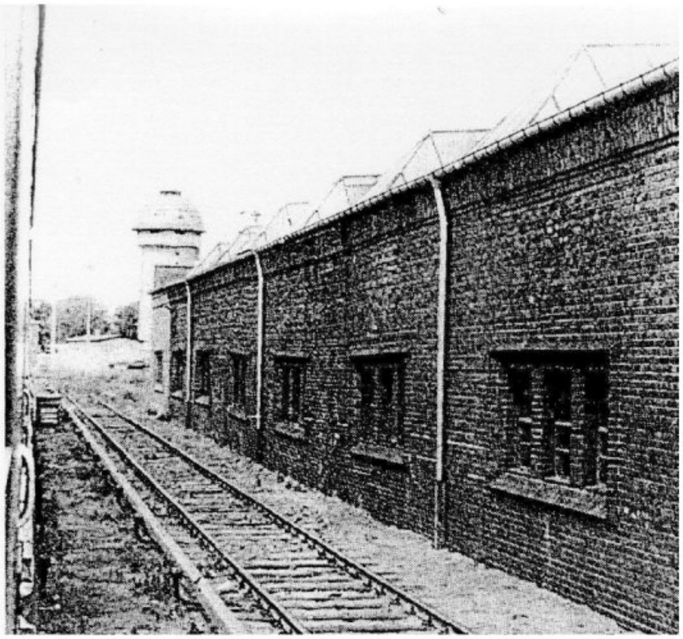


Figure 2: Building near a "S-Bahn railway"

$\dot{\sigma}$-$\dot{\varepsilon}$- constitutive models are used for this purpose. During the implicit cycles the strain loop is recorded as a series of discrete strain states for each integration point in the FE model. From the recorded strain loop the strain amplitude $\varepsilon^{\text{ampl}}$ is calculated (the procedure is explained later on) which is an important input parameter for the explicit part of the calculation. Larger packages of cycles are calculated explicitly using a special High-Cycle Accumulation (HCA) model. The HCA model predicts the development of the residual strain with the number of cycles without tracing the strain path during the individual cycles. The basic equation of HCA models reads

$$\dot{\sigma} = \mathsf{E}:(\dot{\varepsilon} - \dot{\varepsilon}^{\text{acc}}) \tag{1}$$

with E being an elastic stiffness and $\dot{\varepsilon}^{\text{acc}}$ being the prescribed rate of strain accumulation. HCA models work similar to viscoplastic models with the number of cycles *N* replacing the time *t*. Therefore, the accumulation of deformations under cyclic loading is treated similar to the problem of creep under constant load. After several thousand cycles it may be necessary to update the spatial field of the strain amplitude in a so-called "control cycle" (Figure 4b) which is calculated implicitly.

Such a HCA model has been recently proposed by Niemunis *et al* (2005). It is based on an extensive experimental program with cyclic triaxial tests and cyclic multidimensional shear tests on sand (Wichtmann, 2005;Wichtmann et al., 2007). The HCA model considers the influence of the strain amplitude, of the actual state of the soil (average void ratio, average stress) and of the cyclic preloading (number of cycles in the past).

For a number of practical problems the strain loops in the soil due to a cyclic loading are approximately one-dimensional, for example for processes with small loading frequencies (filling of tanks, watergates) or for stationary harmonic excitations (machine foundations). Also in the case of offshore wind power plants, where the foundations are cyclically loaded due to wind and waves, the strain loops are mainly one-dimensional, although the direction of the cycles (polarization) may change due to the changing wind direction.

Complicated multidimensional strain loops in the soil may result from earthquakes (Figure 5), from moving traffic loads or near railroads (Figure 6) due to wave propagation. Influence of the strain loop shape on the rate of strain accumulation and the handling of complicated multi-dimensional strain loops in a HCA model is disscussed in the following sections. The open questions will be studied within the framework of a research project which is outlined at the end.

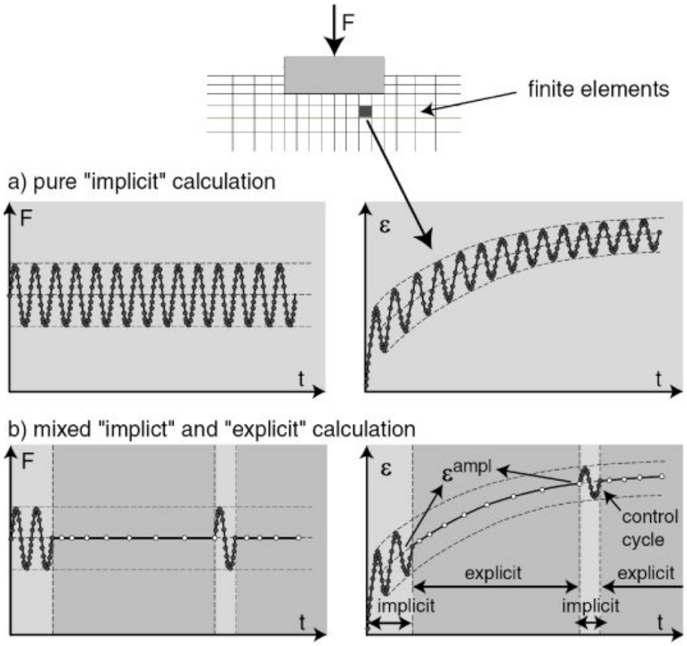


Figure 4: FEM calculation of the settlement of a shallow foundation under cyclic loading: a) Pure implicit versus b) combined implicit and explicit calculation

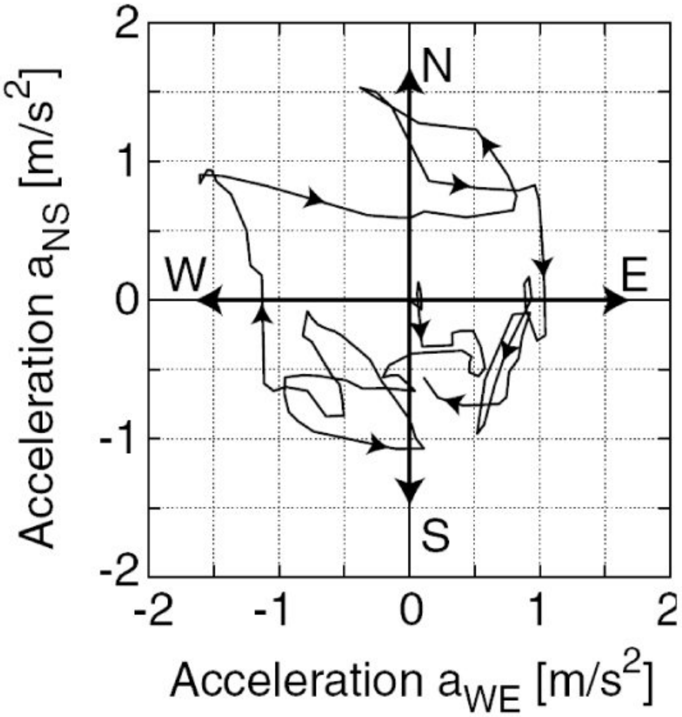


Figure 5: Complicated acceleration loops due to the 1964 Niigata earthquake (Ishihara, 1993)

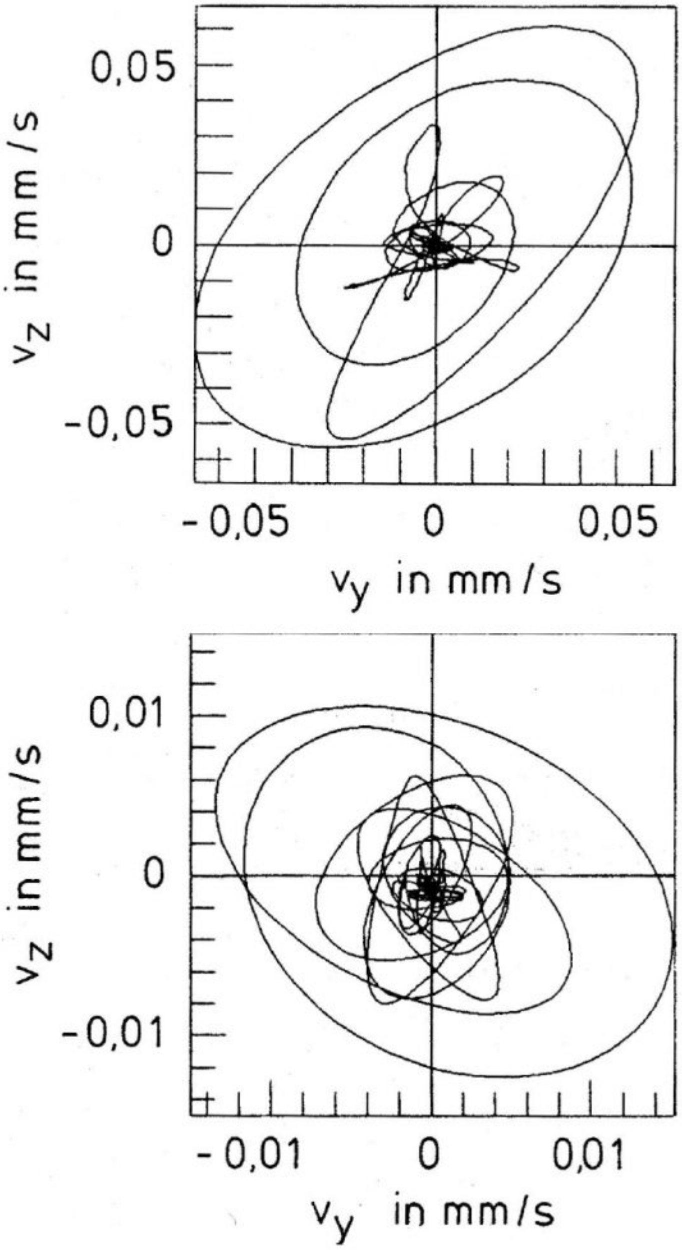


Figure 6: Complicated velocity loops due to traffic loading, measurements of Huber (1988)

INFLUENCE OF THE STRAIN LOOP SHAPE ON THE RATE OF STRAIN ACCUMULATION

There is some experimental evidence that the shape of the strain loop signifcantly influences the accumulation of residual strain. Pyke *et al.* (1975) subjected a dry sand layer to a multiaxial cyclic loading. Two shaking tables were used. One was mounted transversely on the other one, allowing for 2-D shearing.

If approximately circular shear stress cycles were applied, the settlements were twice larger than for uniaxial cycles with the same maximum shear stress (Figure 7a). Furthermore, if two stochastically generated loadings $\tau_1(t)$ and $\tau_2(t)$ with $\tau_1^{ampl} \approx \tau_2^{ampl}$ were applied simultaneously, the resulting settlement was twice larger than in the case where the sand layer was sheared only with $\tau_1(t)$ or only with $\tau_2(t)$ (Figure 7b). If the shaking tables were additionally accelerated in the third, vertical direction, the accumulation rate was even larger (Figure 7b). The conclusion of the test results was that if sand is cyclically sheared simultaneously in several orthogonal directions, the resulting settlement is identical with the sum of the settlements which would result from an uniaxial cyclic shearing in the individual directions.

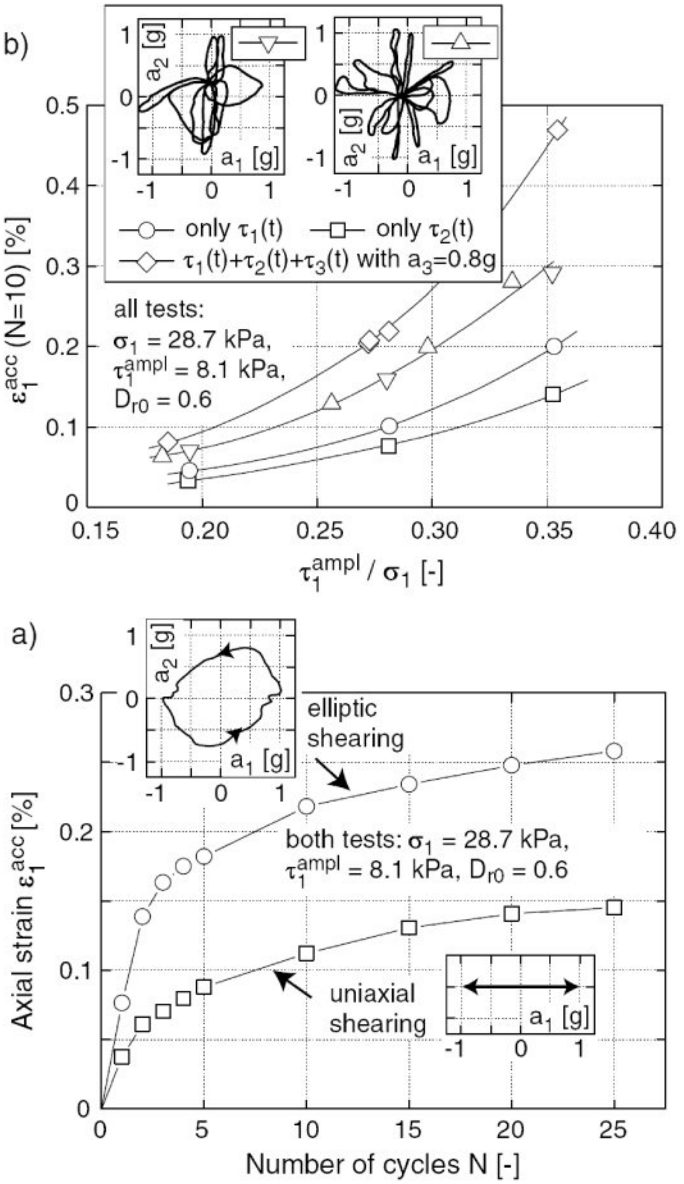
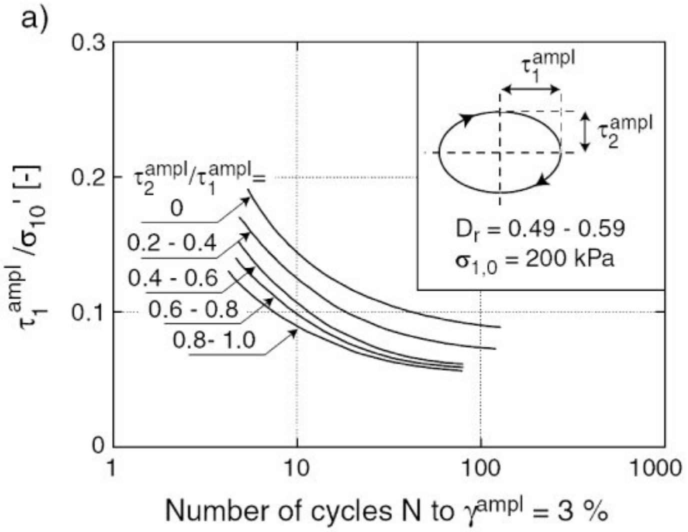


Figure 7: Shaking table tests of Pyke *et al.* (1925): a) Comparison of uniaxial and circular stress cycles, b) effect of stochastically generated cycles

In undrained cyclic tests the pore water pressure accumulates instead of the volumetric strain. Ishihara & Yamazaki (1980) performed undrained simple shear tests with a stress controlled shearing in two mutually perpendicular directions.

In a first series elliptic stress cycles were tested. The amplitude τ_1^{ampl} was kept constant and the amplitude in the orthogonal direction was varied in the range $0 \leq \tau_2^{ampl} \leq \tau_1^{ampl}$ (Figure 8a). With increasing ratio $\tau_2^{ampl} / \tau_1^{ampl}$, the accumulation of excess pore water pressure was accelerated and the liquefaction (defined as the time at which a shear strain amplitude γ^{ampl} = 3 % was reached) was achieved after a lower number of cycles (Figure 8a). In a second series of tests, the specimens were sheared alternatingly in the τ_1- and the τ_2- direction (Figure 8b). A cycle was completed when both shearing directions were passed. Also in these tests, the liquefaction resistance decreased with an increasing ratio $\tau_2^{ampl} / \tau_1^{ampl}$.

In order to develop the HCA model multidimensional simple shear tests were performed by Wichtmann *et al.* 200, wich showed a twice larger accumulation rate for a circular shearing compared to one-dimensional cycles with the same maximum span (Figure 9). Thus, the accumulation rate increases with increasing number of dimensions run through by the strain path. The influence of the cycle shape can also be tested in cyclic triaxial tests with a simultaneous variation of the axial stress σ_1 and the lateral stress σ_3. Niemunis *et al.* (2007) tested different cycle shapes in the p-q-plane with p = $(\sigma_1 + 2\sigma_3)$ /3 being the mean effective stress and q = $\sigma_1 - \sigma_3$ being the deviatoric stress. The resulting curves of the residual strain ε^{acc} versus the number of cycles *N* are given in Figure 10. Again two-dimensional loops produce larger residual strains than one-dimensional.



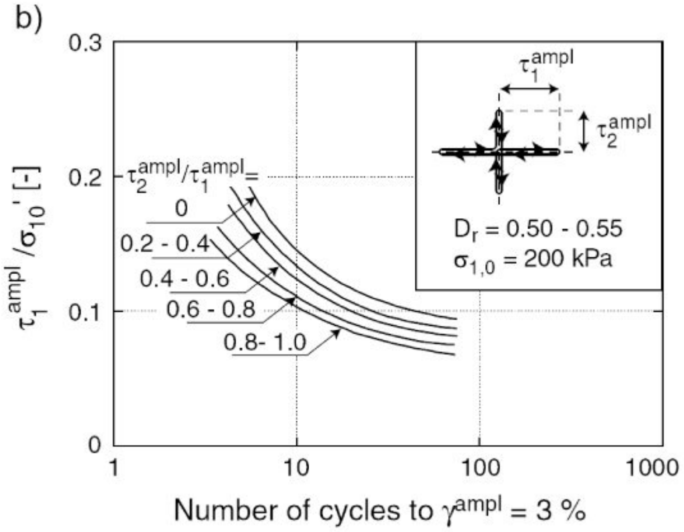


Figure 8: Influence of the shape of the stress cycles on the liquefaction resistance after Ishihara & Yamazaki(1980) : a) elliptic cycles, b) alternating cycles (σ_{10}' is the initial axial effective stress)

cycles. In the case of one-dimensional cycles, a single change of the polarization by 90º undertaken at $N = 1{,}000$ lead to an increase of the strain accumulation rate. This effect was also observed in multidimensional simple shear tests (Wichtmann *et al.*, 2007). Although the two-dimensional loops all had the same spans in the *p*- and in the *q*-direction, there are some differences in the accumulation rates depending on the loops shape, circle, diamond or cross, (see Figure 10).

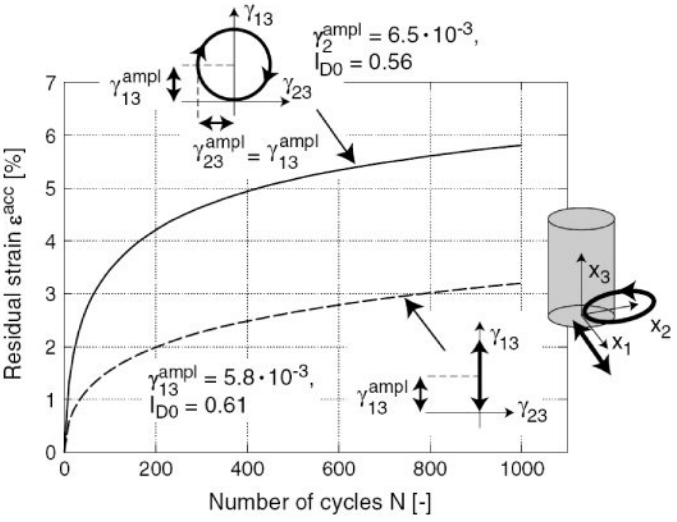


Figure 9: Comparison of circular and one-dimensional strain loops in simple shear tests, Wichtmann *et al.* (2007)

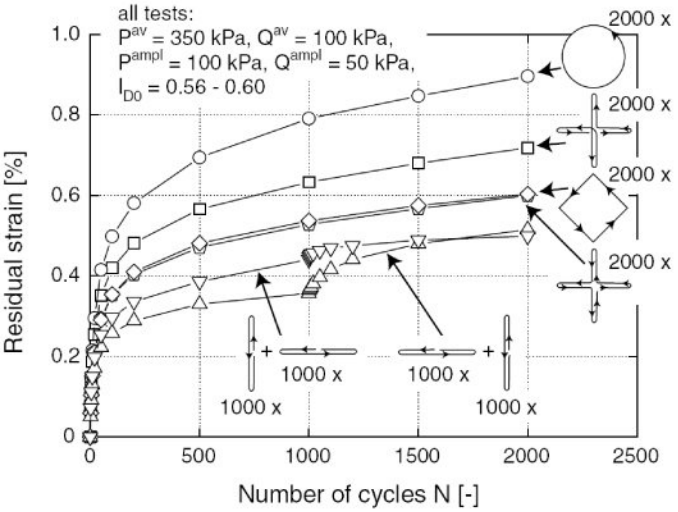


Figure 10: Accumulation curves measured in triaxial tests with a simultaneous cyclic variation of σ_1 and σ_3, Niemunis *et al.*(2007) ($P = \sqrt{3}p$, $Q = \sqrt{2/3}q$)

It may be concluded that the influence of the strain loop shape on the accumulation rate is quite significant and that it has to be considered in a HCA model. More experimental work is necessary in order to understand better the effect of more complex multi-dimensional strain loops (*e.g.* in order to understand the differences shown in Figure 10).

AMPLITUDE DEFINITION FOR MULTI-DIMENSIONAL CONVEX STRAIN LOOPS

The HCA model of Niemunis *et al*. (2005) contains a definition of a tensorial amplitude for multi-dimensional strain loops (see also Niemunis, 2003). However, this definition is only applicable to convex strain loops. The procedure for the determination of ε^{ampl} starts from the series of discrete strain points recorded during the implicitly calculated cycles (Figure 4). First, the span $2R^{(6)}$ (a scalar variable) of the in general six-dimensional strain loop is determined. The direction of the line connecting the two most distant points of the loop is denoted by $\vec{r}^{(6)}$ (a second order tensor, *i.e.* r_{ij}). After that the loop is projected into the direction $\vec{r}^{(6)}$ onto a (hyper-) plane. The projected loop is five-dimensional. The span $2R^{(5)}$ and the direction $\vec{r}^{(5)}$ of the projection are determined,and so on. Having finished the projections (in Figure 11 they are illustrated startingfrom a three-dimensional loop) six spans $2R^{(6)} \ldots 2R^{(1)}$ and six directions $\vec{r}^{(6)} \ldots \vec{r}^{(1)}$ are available. The fourth-order tensor of the amplitude A_ε is then calculated as the sum of the dyadic products of the directions $\vec{r}^{(n)} \otimes \vec{r}^{(n)}$ weighted with the respective half span $R^{(n)}$:

$$\mathsf{A}_\varepsilon = \sum_{n=1}^{6} R^{(n)}\, \vec{r}^{(n)} \otimes \vec{r}^{(n)} \qquad (\text{i.e.} A_{ijkl} = \sum_{n=1}^{6} R^{(n)}\, r_{ij}^{(n)}\, r_{kl}^{(n)}) \quad (2)$$

As a scalar measure the norm of the amplitude tensor A_{ε} is used.

$$\varepsilon^{\mathrm{ampl}} = \left\| \mathsf{A}_{\varepsilon} \right\| \tag{3}$$

In the special case of one-dimensional strain loops the scalar measure defined by Equations (2) and (3) is identical with the classical definition of the amplitude $\varepsilon^{\mathrm{ampl}} = (\varepsilon^{\max} - \varepsilon^{\min})/2$. For two-dimensional elliptical cycles one obtains $\varepsilon^{\mathrm{ampl}} = \sqrt{(R^{(1)})^2 + (R^{(2)})^2}$. Thus, circular loops with $R^{(1)} = R^{(2)} = R$ have an amplitude $\varepsilon^{\mathrm{ampl}} = \sqrt{2R}$.

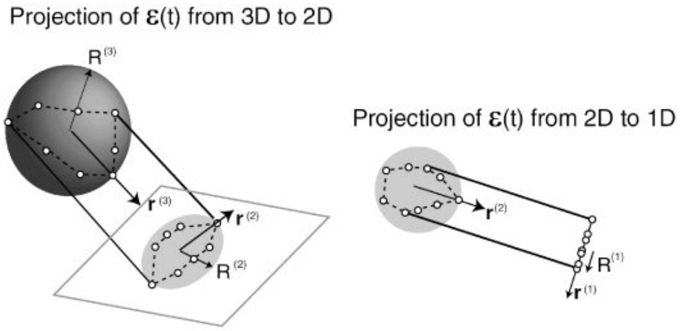


Figure 11: Multiple procetion of a strain loop in order to calculate an amplitude for multi-dimensional loops

As could be demonstrated experimentally (Wichtmann *et al.* (2005), the rate $\dot{\varepsilon}^{\mathrm{acc}}$ of strain accumulation is proportional to the square of the strain amplitude $(\varepsilon^{\mathrm{ampl}})^2$. This dependence has been also implemented into the HCA model. Thus, for two-dimensional circular strain loops with a radius R (amplitude $\varepsilon^{\mathrm{ampl}} = \sqrt{2}R$) the accumulation model predicts twice larger accumulation rates than for one-dimensional cycles with a span $2R$ (amplitude $\varepsilon^{\mathrm{ampl}} = R$).

The prediction of a twice larger accumulation rate for circularcycles is in good accordance with the test results shown in Figure 9. Thus, the amplitude definition for convex strain loops could be confirmed for the two-dimensional case.

AMPLITUDE DEFINITION FOR MORE COMPLICATED STRAIN LOOPS

It has been recognized that the amplitude definition presented in Section 3 may not properly describe the accumulation rates due to more complicated strain loops as thoseshown in Figures 5 and 6 or those presented in Figure 12 (which have been generated bya superposition of harmonic functions). The definition of an amplitude and the counting of the cycles for such loops is not clarified yet.

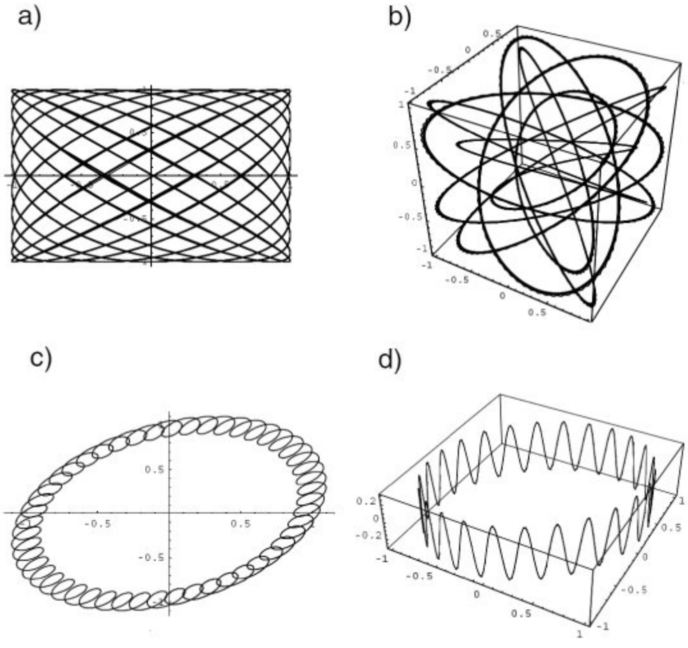


Figure 12: Complicated strain loops, obtained by superposition of sine functions a) and b) with slightly different frequencies and amplitudes or c) and d) with very different frequencies and different amplitudes

A proposal for the treatment of such strain loops has been already made by Niemunis *et al.* (2007). It is presented in the following. It has to be stressed that this procedure has not been verifed experimentally yet.

The strain path $\varepsilon_{ij}(t)$ is assumed as a superposition of individual harmonic oscillations.The oscillations dier by their frequency *fK* (or by their angular velocity $\omega_K = 2\pi f_K$). First, the single oscillations are extracted from the entire signal. For eachstrain component $\varepsilon_{ij}(t)$ the portions belonging to a certain frequency *fK* are extracted.Their sum constitutes a harmonic oscillation. In the general case it is a six-dimensional ellipse in the strain space. The oscillations are numbered with the index K. The signal $\varepsilon_{ij}(t)$ is approximated as a sum of M oscillations:

$$\varepsilon_{ij}(t) \approx \sum_{K=1}^{M} \varepsilon_{ij}^{\mathrm{ampl}K} \sin\left(\omega^{K} t + \varphi_{ij}^{K}\right) \tag{4}$$

The signal portions belonging to a certain frequency are filtered from the entire signal by means of a spectral analysis. For each strain component the amplitude $\varepsilon_{ij}^{\mathrm{ampl}K}$ and the phase shift φ_{ij}^{K} corresponding to the angular velocity ω^{K} are determined. The procedure is described in detail in by Niemunis *et al.* (2007). Since the accumulation rate depends on the square of the strain amplitude, only the frequencies *fK* with large amplitudes $\varepsilon_{ij}^{\mathrm{ampl}K}$ are considered. For each oscillation the scalar measure of the strain amplitude is determined.

$$\varepsilon^{\mathrm{ampl}\,K} = \left\| \varepsilon^{\mathrm{ampl}\,K} \right\| \tag{5}$$

Where $\varepsilon^{\mathrm{ampl}\,K}$ being a second order tensor collecting the amplitudes of the individual strain components ε_{ij} of the oscillation K. The same value $\varepsilon^{\mathrm{ampl}\,K}$ would result from the procedure described in the previous section when it is applied to a strain loop where allstrain components are described by harmonic functions with amplitudes $\varepsilon_{ij}^{\mathrm{ampl}K}$. If *M* oscillations (i.e. *M* different frequencies) have to be considered the entire signalis decomposed into *M* packages of cycles each with an amplitude $\varepsilon_{ij}^{\mathrm{ampl}K}$ and a number of cycles *N*. It is assumed that these packages can be calculated in arbitrary sequence and that in this way the residual deformations can be estimated. It has been demonstrated experimentally by Wichtmann *et al*. (2006), that the sequence of packages ofone-dimensional cycles with different amplitudes is of minor importance for the value of the permanent strain at the end of a test (Figure 13).

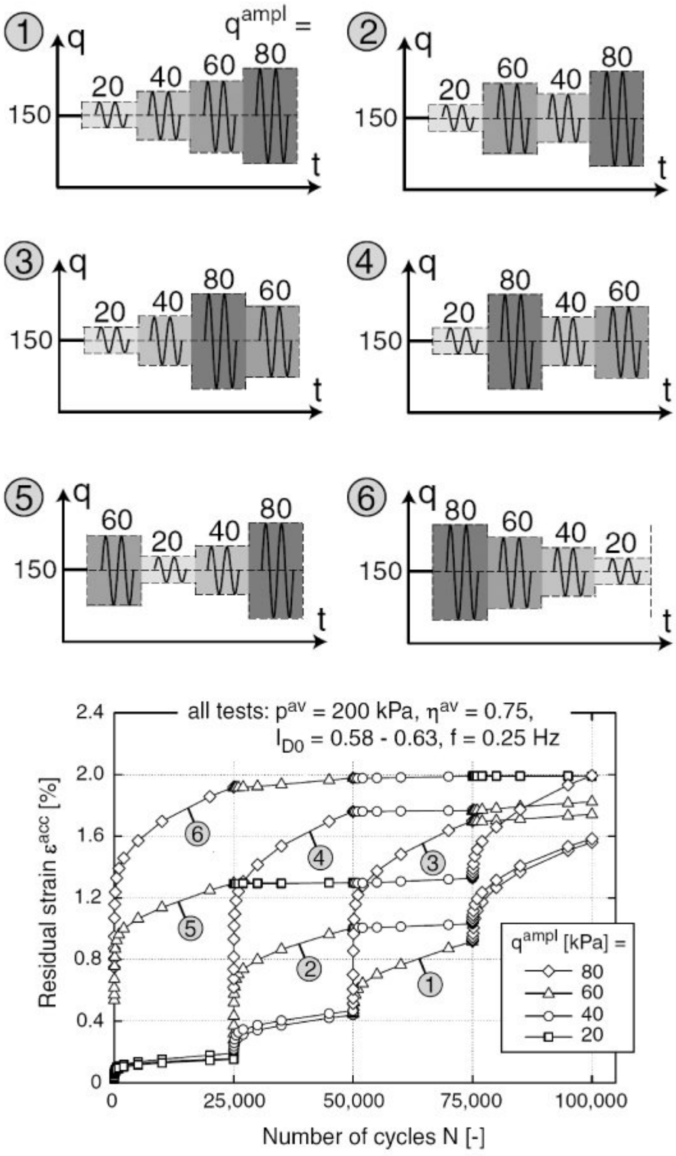


Figure 13: Cyclic triaxial tests with four packages of cycles each with different amplitudes q^{ampl} = 20, 40, 60 or 80 kPa applied in six different sequences, (Wichtmann *et al*., 2005; 2006)

However, it has not been experimentally confirmed yet that the sequence of the packages can also be neglected in the case of multi-dimensional cycles. Furthermore, it has not been experimentally verified whether the decomposition of a complicated load signal intosingle oscillations as described above is justified. Such a study will be undertaken within the scope of a research project which is outlined in the following section.

OUTLINE OF A RESEARCH PROJECT

EXPERIMENTAL PART

As outlined above, it is necessary to clarify whether a complicated strain loop can be decomposed into several oscillations where each oscillation collects the strain components belonging to a certain frequency *fK*. It has also to be checked experimentally if these oscillations can be treated separately and if the sequence of application of the oscillations is insignificant.

For this purpose cyclic triaxial tests will be performed. In the axially symmetric triaxial test only two-dimensional loops can be tested. A cyclic variation of more than two straincomponents would be possible in hollow cylinder triaxial or "true" triaxial devices whichare not available for the present study. Therefore, the applicability of the findings from the triaxial tests to more than two dimensions has to be assumed. Strain loops will be tested which are obtained by a superposition of several harmonic functions with different frequencies and amplitudes (see the example in Figure 14). For comparison, other tests will be performed on fresh samples, in which the same oscillations are applied separately in succession. The sequence of application of the oscillations will also be varied.

A decomposition of a strain loop into oscillations according to theprocedure described in Section 4 is justified if the tests with the complicated strain loopsand those with the oscillations applied in succession deliver similar residual strains. The number of superposed harmonic functions will be varied as well as their amplitudes and frequencies. Quite different strain loops may result (Figure 12).

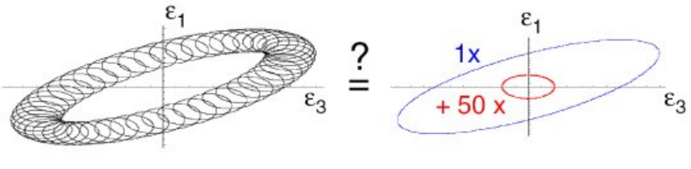


Figure 14: Decomposition of a two-dimensional strain loop in two oscillations with different frequencies *fK*

The triaxial tests will be performed drained and stress controlled with a simultaneousoscillation of the axial stress σ_1 and the lateral stress σ_3. However, if the lateral stress is varied in a triaxial test, the measurement of lateral deformations of the sample becomes a problem. If the wide spread measurement of volume changes via the squeezed out or sucked in pore water of fully saturated specimens is used, the measured data is falsified by membrane penetration effects (Figure 15). If σ_3 is increased the rubber membrane surrounding the specimen is pressed into holes between the grains and the water in these holes is squeezed out. The volume of this squeezed out water is wrongly attributed to acompaction of the grain skeleton. Membrane penetration is negligible only for very fine sands. For medium coarse and coarse sands the portion of the measured volume changecaused by membrane penetration may be signifficant. The membrane penetration has no effect on the measurement of residual deformations, but for the measurement of the strain loop it is of essential importance. An accurate measurement of the axial and of the lateral strains, that means a precise knowledge of the strain loop, is of crucial importance for achieving the aims of this research project. Therefore the strain must be measured locally directly on the specimen. LDTs (local displacement transducers, are shown in Figure 16 (Goto *et al*., 1991; Hoque *et al*. 1997). LDTs are strips of phosphor bronze which are set up with strain gauges. The LDTs are mounted on the specimen in a slightly bended condition by means of hinges gluedto the rubber membrane. The sensors recognize deformations as changes of bending. LDTs may be used for the measurement of axial (Figure 16 right) and lateral (Figure 16 left) deformations. A specimen with a square cross section is advantageous for the measurement of lateral deformations with LTDs.

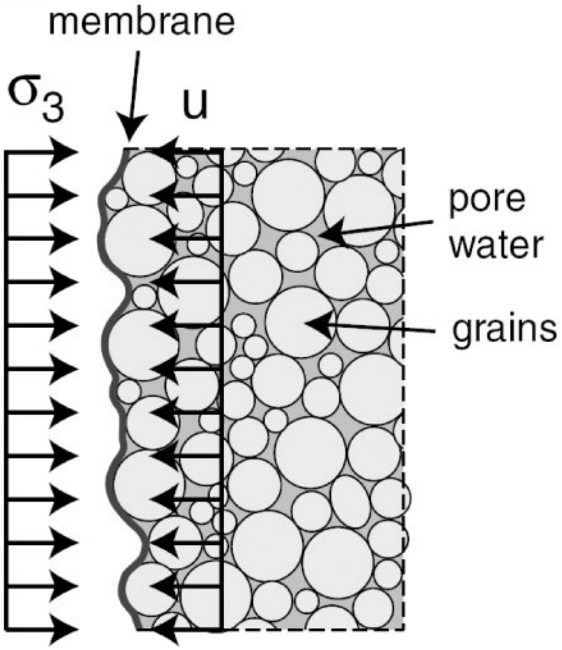


Figure 15: Falsification of volume change measurements via the pore water due to membrane penetration effects

Figure 16: Measuring local strains of prismatic specimens using LDT, Rondón *et al.*

A fine sand will be used as the testing material since membrane penetration effects are small and because the accumulation rate increases with decreasing grain size (Wichtmann *et al*., 2007; 2005), so that differences in the accumulation rate may be worked out more clearly. Based on the test results it has to be judged if the decomposition of complicated loopsinto single oscillations according to the proposed procedure is sufficiently accurate forpredictions of residual deformations in the soil due to cyclic loading.

NUMERICAL PART

FE calculations will be performed using the program ABAQUS. The HCA model is available as a user defined subroutine UMAT. Up to now only the definition for convex strain loops has been implemented into the UMAT. For the application of the HCA model to problems with complicated strain loops the (eventually modified) procedure for such loops has to be programmed into the UMAT.

Boundary value problems similar to that shown in Figure 17 will be studied by meansof the FEM. It is intended to recalculate settlements of real buildings near railways,for which in situ measurements are documented in the literature. Because of the spatial impact of the loading due to passing trains the calculations have to be performed three-dimensionally. The loading due to a passing train has to be considered correctly.

The dynamic FE calculation of wave propagation can be performed using an elastic constitutive model for the soil since the amplitudes are small. It is followed by a calculation of theresidual deformations with the HCA model. The lower and the lateral boundaries of the FE model are modelled such that no reflections of waves take place.

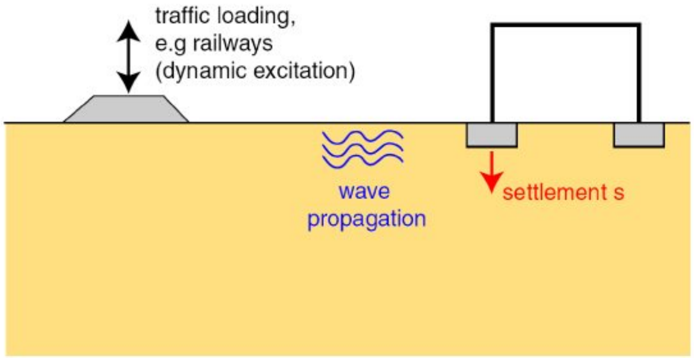


Figure 17: Possible system for FE calculations: Building near a railway

SUMMARY AND CONCLUSIONS

The paper demonstrates that the shape of the strain loop significantly influences the rate of strain accumulation due to a drained cyclic loading. A definition of an amplitude for convex multi-dimensional strain loops is explained.

This definition is experimentallyconfirmed for the two dimensional case. It is incorporated into a high cycle accumulation (HCA) model for sand. The applicability of a novel procedure for more complicated strain loops will be checked experimentally in the framework of a research project. The procedure uses a decomposition of the signal into several harmonic oscillations. These oscillations diffier in their frequency and are treated separately. The working programme ofhe research project is outlined in the paper.

ACKNOWLEDGEMENTS

The research will be done at the IBF in the framework of the PhD scholarship of M. Poblete which is founded by DAAD and CONICYT. We gratefully acknowledge this financial support.

REFERENCIAS

Goto S., Tatsuoka F., Shibuya S., Kim Y.S. , and Sato T. (1991). A simple gauge for local small strain measurements in the laboratory. *Soils and Foundations*, **31** (1): 169-180

Heller H.J. (1981). Bauwerkssetzungen bei sandigem Untergrund infolge von Erschütterungen durch Bahnverkehr. *Baumaschine und Bautechnik*, **35** (2): 56-61

Hoque E., Sato T., and Tatsuoka F. (1997). Performance evaluation of LDTs for use in triaxial tests. *Geotechnical Testing Journal*, ASTM, **20** (2):149-167

Huber G. (1988). Erschtterungsausbreitung beim Rad/SchieneSystem. Promotion, Institut für Bodenmechanik und Felsmechanik der Universität Fridericiana in Karlsruhe, Heft Nr. **115**

Ishihara K. (1993). Liquefaction and Low failure during earthquakes. The 33rd Rankine Lecture. *Geotechnique*, **43** (3): 351-415

Ishihara K. and Yamazaki F. (1980). Cyclic simple shear tests on saturated sand in multi-directional loading. *Soils and Foundations*, **20** (1): 45-59

Niemunis A. (2000) Akkumulation der Verformung infolge zyklischer Belastung - numerische Strategien. In Beiträge zum Workshop: Boden unter fast zyklischer Belastung: Erfahrungen und Forschungsergebnisse, Veröentlichungen des Institutes für Grundbau und Bodenmechanik, Ruhr-Universität Bochum, Heft Nr. **32**, pages 1-20

Niemunis A. (2003). Extended hypoplastic models for soils. Habilitation, Veröentlichungen des Institutes für Grundbau und Bodenmechanik, Ruhr Universität Bochum, Heft Nr. **34** available from www.pg.gda.pl/aniem/anliter.html.

Niemunis A. and Herle I. (1997). Hypoplastic model for cohesionless soils with elastic strain range. Mechanics of Cohesive-Frictional Materials, **2**: 279-299

Niemunis A., Wichtmann T. and Triantafyllidis T. (2005). A high-cycle accumulation model for sand. *Computers and Geotechnics,* **32** (4): 245-263

Niemunis A., Wichtmann T. and Triantafyllidis Th. (2007). On the denition of the fatigue loading for sand. In International Workshop on Constitutive Modelling - Development, Implementation, Evaluation, and Application, 12-13 January 2007, Hong Kong

Pyke R., H.B. Seed, and Chan C.K. 81975). Settlement of sands under multidirectional shaking. *Journal of the Geotechnical Engineering Division*, ASCE, **101** (GT4): 379-398

Rondon H.A., Wichtmann T., Triantafyllidis Th, and A. Lizcano. Comparison of cyclic triaxial behavior of unbound granular material under constant and variable conning pressure (accepted for publication). *Journal of Transportation Engineering*

Von Wolersdor P. A. (1996). A hypoplastic relation for granular materials with a predened limit state surface. *Mechanics of Cohesive-Frictional Materials*, **1**: 251-271

Wichtmann T. (2005). Explicit accumulation model for non-cohesive soils under cyclic loading. Dissertation, Schriftenreihe des Institutes für Grundbau und Bodenmechanik der Ruhr Universität Bochum, Heft 38, available from www.rz.uni-karlsruhe.de/gn97

Wichtmann T., Niemunis A. and Triantafyllidis T. (2005). Strain accumulation in sand due to cyclic loading: drained triaxial tests. *Soil Dynamics and Earthquake Engineering*, **25** (12): 967-979

Wichtmann T., Niemunis A. and Triantafyllidis T. (2007). On the influence of the polarization and the shape of the strain loop on strain accumulation in sand under high-cyclic loading. *Soil Dynamics and Earthquake Engineering*, **27** (1): 14-28

Wichtmann T., Niemunis A. and Triantafyllidis T. (2007). Strain accumulation in sand due to cyclic loading: drained cyclic tests with triaxial extension. *Soil Dynamics and Earthquake Engineering*, 27 (1): 42-48

Wichtmann T., Niemunis A., and Triantafyllidis Th. (2006). Gilt die Miner'sche Regel für Sand Bautechnik, **83** (5): 341-350

Wichtmann T., Niemunis A. and Triantafyllidis Th. (2007). Recent advances in constitutive modelling of compaction of granular materials under cyclic loading. In N. Bazeos, D.C. Karabalis, D. Polyzos, D.E. Beskos, and J.T. Katsikadelis, editors, Proc. of 8th HSTAM International Congress on Mechanics, Patras, Greece 12 14 July, volume **1**, pág: 121-136,

Wichtmann T. and Triantafyllidis Th. (2005). Über den Einfluss der Kornverteilungskurve auf das dynamische und das kumulative Verhalten nichtbindiger Böden. Bautechnik, **82** (6): 378-386

Concurso Académico

La Universidad Católica de la Santísima Concepción, en el marco de su Plan de Desarrollo Estratégico, llama a concurso acedémico para proveer el cargo de jornada completa (JC), para el Departamento de Ingeniería Civil de la Facultad de Ingeniería.

INGENIERO CIVIL

Grado de Doctor en Ingeniería, ya sea en el área de Construcción, Transporte, Hidráulica, Estructuras ó Geotecnia. Experiencia en la Ingeniería práctica

1.- El cargo es académico con funciones de docencia de pre y postgrado, investigación y extensión
2.- La preselección se realizará por los antecedentes de acuerdo a los requisitos definidos por el cargo
3.- Se realizará una entrevista personal a los concursantes preseleccionados
4.- La Universidad Católica de la Santísima Concepción se reserva el derecho de declarar desierto el concurso
5.- Los antecedentes enviados no serán devueltos

Antecedentes:

1.- Carta de presentación, indicando pretenciones de renta y el código del cargo al cual concursa
2.- Currículum Vitae. Fotocopias de certificados de título y grados, debidamente legalizadas
3.- Plan de trabajo o proyecto de desarrollo académico que fundamenta su postulación
4.- Dos cartas de recomendación (en sobre cerrado)

Enviar antecedentes a: Concurso Académico Ingeniería Civil, Facultad de Ingeniería, Departamento de Ingeniería Civil, Alonso de Rivera 2850, Concepción, Chile

Facultad de Ingeniería, Alonso de Rivera 2850, teléfonos: (56-41) 273 53 03, fax: (56-41) 273 53 00

Requerimientos de publicación

1. Los autores deben indicar la categoría de clasificación del artículo, la cual puede ser: artículo técnico (investigación), nota técnica (artículo corto), informe técnico (de diseños, construcciones, monitoreos, etc.), discusión o comentario (de material publicado previamente). Los artículos enviados deberán ser originales y no haber sido publicados antes ni estar en proceso de revisión por otra revista. Ellos pueden ser escritos en inglés o español y deberán ser enviados en versión electrónica en formato word o pdf. Los artículos se envían al Editor Prof. Mauro Poblete vía correo electrónico a oyp@ucsc.cl (preferido) o en CD vía correo postal a Departamento de Ingeniería Civil, Universidad Católica de la Santísima Concepción, Alonso de Ribera 2850, Casilla 2, Concepción, Chile. Deberá incluirse en el envío la dirección postal y electrónica de todos los autores. Una vez que el artículo es recibido conforme a las guías de más abajo, este será enviado a expertos en los temas específicos para su revisión. El Editor podrá requerir revisiones y correcciones antes de tomar una decisión final de aceptación o rechazo del artículo.

2. El artículo deberá tener una extensión máxima de 8000 palabras, no se exige formato (tipo ni tamaño de letra, espaciamiento, etc.), sólo se pide claridad tanto en lo escrito, o sea, buena redacción con una secuencia lógica de lo que se presenta, como en las figuras, gráficos, tablas y fotos. El formato usado en la revista se encuentra disponible en www.oyp.cl/normas.pdf.

3. Los artículos deberán tener una página de título con el nombre y apellido del o de los autores, su filiación, dirección postal y e-mail. El título debe estar en castellano e inglés.

4. El resumen no debe exceder las 250 palabras en su versión en español y debe apuntar a los aspectos claves del artículo y dar una síntesis de las aplicaciones y conclusiones más importantes que el artículo entrega. El abstract debe ser una traducción correcta del resumen al inglés. Se deben incluir palabras claves tanto en castellano como en inglés.

5. Se usa el sistema Harvard para las referencias. Estas deben estar completas y correctas. En el texto, las referencias deben citarse como sigue:

Martínez (2008) o (Goodell y Warren, 2006). Para más de dos autores debe indicarse como (Van Abeelen *et al*. 2008). Al final del artículo, las referencias deben agregarse en orden alfabético según el apellido del primer autor. Las referencias de un mismo autor de un mismo año deben diferenciarse usando 2008a, 2008b, etc. El estilo de las referencias debe seguir uno de los esquemas siguientes: Cepeda, M. (2006). Un nuevo modelo para la estimación del tiempo de espera en paraderos de transporte público. Obras y Proyectos **2** (1), pág. 36-44

Wichtmann, T., Niemunis, A., Triantafyllidis, Th. and Poblete, M. (2005). Correlation of cyclic preloading with the liquefaction resistance. Soil Dynamics and Earthquake Engineering **25** (12). pp. 923-932

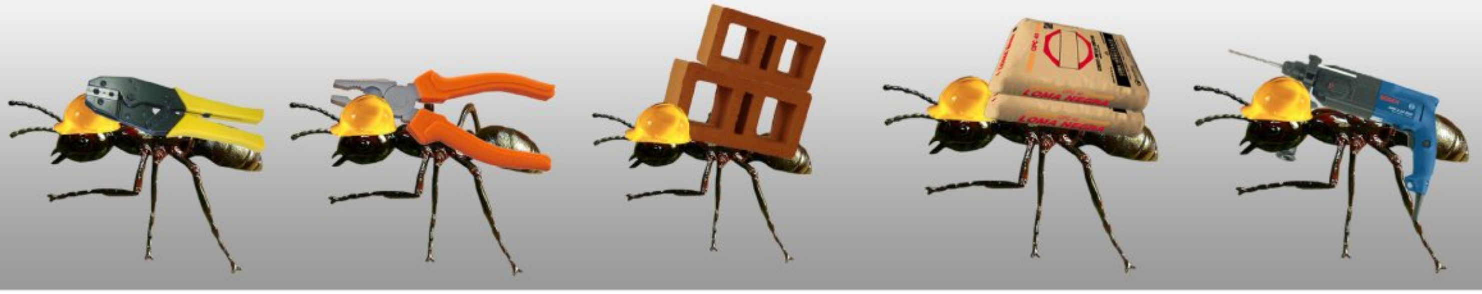
6. Las tablas y fórmulas (ecuaciones) deberán ser numeradas secuencialmente en el mismo orden en que aparecen en el texto, con números arábigos y haciendo referencia a ellas como: Tabla1, Tabla 2, Fórmula (1), Fórmula (2)...etc., según corresponda. Estas deben ser introducidas dentro del texto en el mismo orden en que son referenciadas. En el caso de las tablas, el título debe colocarse en la parte inferior y no deben duplicar los resultados presentados en gráficos. El sistema de unidades a emplear será el Sistema Internacional (SI).

7. Las figuras pueden incluir gráficos, esquemas y diagramas. Las figuras deben enviarse en una condición lista para su publicación, con calidad de impresión láser. Si son fotografías, deben ser de alta calidad. Deben numerarse en forma secuencial, en el mismo orden en que son referenciadas en el texto como: Figura 1, Figura 2, Foto 1, Foto 2, etc. y su título deberá colocarse en la parte inferior. Deberán ser incluidas dentro del texto según sean citadas.

8. Las opiniones vertidas en los artículos publicados en Obras y Proyectos son de exclusiva responsabilidad del autor o los autores de los mismos y no reflejan necesariamente los puntos de vista del Departamento de Ingeniería Civil de la Universidad Católica de la Santísima Concepción.

9. El envío de un artículo a la revista Obras y Proyectos implica que representa un trabajo original, no publicado previamente y no considerado para publicación en ninguna otra parte. Los autores aceptan transferir el derecho de autor de sus artículos a la Editorial siempre y cuando el artículo sea aceptado para publicación. El derecho de autor cubre los derechos exclusivos para la reproducción y distribución del artículo, incluyendo re-impresiones, reproducciones fotográficas, microfilms, escaneo de documentos o cualquier reproducción de naturaleza similar así como traducciones. Permisos para usar figuras deben ser obtenidos por el autor en forma previa al envío del artículo.

Para mayor información sobre Obras y Proyectos visite nuestro sitio web www.oyp.ucsc.cl


LOMA NEGRA
LOMA NEGRA

Riegolart Chile

RIEGO AUTOMÁTICO

Se especializa en el diseño y construcción de Riegos Automáticos, Microriego, Piscinas y Extracción de Aguas Subterráneas proporcionando un servicio personalizado, de alta calidad profesional y originalidad, además brindamos asesorías a nivel nacional.

Sumado a nuestra experiencia, incorporamos tecnología de avanzada en software de diseño computacional, maquinaria y materiales. Utilizamos materia prima de primera calidad, seleccionando las mejores marcas que se adapten a las necesidades del diseño proyectado, en donde fundamentalmente consideramos el éxito de la realización del proyecto, así como las ideas y preferencias de nuestros Clientes.

AREA TECNOLOGIA

- Ingeniería y Construcción de sistemas de Riego.
- Mantención de Riegos Automáticos.
- Ingeniería y Construcción de Piscinas.
- Mantención de Piscinas.
- Extracción de Aguas Subterráneas.
- Mediciones flujo de sistemas actuales.
- Ensayos de recepción y eficiencia de equipos.
- Construcción de Microriego.

AREA INGENIERIA

- Proyectos y estudios de ingeniería.
- Diagnósticos de procesos de riego tecnificado.
- Diagnósticos de uso eficiente de aguas.
- Estudio de Remodelaciones.
- Optimización de procesos y diseños de equipos.
- Servicios de contraparte.

AREA CAPACITACION

- Manuales de operación y mantenimiento.
- Cursos interactivos de capacitación industrial y particulares.
- Capacitación integral.

Riegolart

Víctor Rojas
Fono contacto: 9-7957729
Correo electrónico:riegolart@gmail.com

Nuestra experiencia siempre será su mejor garantía