ABSTRACTS

of the research publications considered in the application assessment;
Dr. Radan Ivanov Ivanov

6. Takada S., Hozumi M., **Ivanov R.**, Seismic force acting in bridge restrainers and reliability evaluation, Memoirs of the Construction Engineering Research Institute Foundation, Japan, 43-B, 2001, pp. 69-82

The article examines the behavior of bridges subjected to earthquake, the superstructure of which consists of one body, namely a bridge with several pillars and a superstructure of a continuous beam. The behavior regarding the failure of the bearings and the forces arising in the cable restrainers under the impact of design earthquakes from the Japanese norms for bridge design are analyzed. In the model used, the pillars and columns are modeled with frame elements, the superstructure as an ideal rigid body, the restrainers as tension-only springs. After breaking of the neoprene bearings, the tension is switched off, and friction with or without sliding occurs. Six real earthquake records were used in the study. Two types of "instantaneous" and "delayed" restrainer activation have been identified, with the former being activated immediately after bearing failure and the latter after a number of oscillation cycles. The "instantaneous" type of activation leads to greater efforts in the restrainers. It was found that the forces in the "instantaneous" type of activation are higher at a lower coefficient of friction after bearing failure, while in the type of activation "delayed" the dependence is reversed. It was found that the forces in the restrainers are a function of the weight of the superstructure and not of the support reactions, as specified in the Japanese norms. A theoretical-empirical method for determining the force is proposed, without the need to make an analysis of the structure. It was found that the forces in the restrainers can increase by up to 50% if the structure is exposed to the two horizontal earthquake components simultaneously, and the influence of the vertical component is negligible.

7. **Ivanov R.**, Takada S., Dynamic failure analysis of cable structures by the DEM method, 13 Symposium of the Kansai chapter of the JSCE, Japan, 2001, I-16-1 - I-16-2

A new hybrid Discrete Element Method (DEM)-lattice approach is proposed which deals with the structure at macro-level, while taking full advantage of the most important feature of time-domain analysis – continuous real time monitoring of structural behaviour. The structural mass is lumped to the nodes. Each mass then stands for a discrete element in terms of the DEM. The structural members between nodes are represented by springs with initial stiffness directly calculable from the axial stiffness of the member. Supports are defined by specifying motion restraints to some elements as appropriate. Material nonlinearity can be incorporated by a suitable choice of a load-deformation curve for the springs. The performance of the method is demonstrated by simulating a cable fixed at both end, and comparing the results to the theoretical solution. Then a rectangular cable grid is loaded by a large force in the middle, and the process of failure, as well as the post failure behavior is successfully monitored.

8. **Ivanov R.**, Takada S., Discrete element analysis for failure analysis of steel pipes crossing active faults, 26 Earthquake engineering symposium, Japan, 2001, pp. 1329-1332

A specialised DEM method for the failure analysis of shell structures made of steel is presented. Hereby, a shell is represented by an equivalent lattice. The in-plane stiffness of shells is represented by a lattice of energy equivalent normal springs, and the bending stiffness of walls is represented by bending springs. The ability of the method to simulate highly non-linear situations is demonstrated by an analysis of a cylinder pinched perpendicularly to its axis by a force couple. A case study was carried out on a pipe in the Fengyuan region in Taiwan that sustained damage during the Chi-Chi Earthquake.

10. **Ivanov R.**, Takada S., Discrete element method for the dynamic buckling analysis of frames, 56 Annual conference of the JSCE, Japan, I-B262, 2001, pp. 524- 525

A new Discrete Element Method (DEM) approach is proposed allowing detailed investigation of buckling and post buckling behaviour in real time. The structural mass is lumped to the nodes. Rotational inertia is also assigned to nodes. Each mass stands for a discrete element in terms of the DEM. Prescribed force, acceleration and velocity time histories can be applied to loaded nodes. The structural members between nodes are represented by springs with initial axial stiffness directly calculable from the axial stiffness of the member, and bending and shear springs of Bernoulli type. Supports are defined by specifying motion restraints to some elements as appropriate. Material nonlinearity can be incorporated by a suitable choice of the axial load-deformation curve for the springs. Elastic-plastic hysteretic model with strain stiffening was used for modelling steel. The method was verified by comparing the results for a strut fixed at both ends and subjected to a compressive force, and then used to simulate dynamic buckling at various loading speeds and imperfection types.

11. Takada S., **Ivanov R.**, Questioning the existence of ultrahigh-frequency seismic waves based on DEM analysis of gate columns, JSCE, Journal of structural engineering, Japan Vol. 48A, 2002, pp. 531-536

In this paper, qualitative evaluation of the potential for jumping of column crowns under several types of dynamic disturbances is performed. It was found that typical vertical earthquake motion cannot cause notable separation at the column-crown interface. Substantial separation could occur due to short velocity pulses as well as earthquake waves of exceptionally high frequency and huge peak accelerations. However, our numerical results as well as experiments done by others indicate that the effect of pulse input would not be limited to flying off of crown but will as well cause either significant structural damage to the column in the form of tensile cracks that spread over the entire cross section, or pulling of the column together with the footing out of the ground. Discovery of such damage modes in post-earthquake surveys could serve as indirect proof of the existence of ultrahigh-frequency seismic waves.

12. Takada S., Ichinose E., B-J. Shin, W. Chen, **Ivanov R.**, Seismic intensity in the vicinity of a surface fault rupture, Proceedings: Second Japan-Taiwan workshop on lifeline performance and disaster mitigation, Japan, 2002, pp. 142-149

This study reports on the characteristics of the ground motion in the vicinity of the faults line in the Ji-Ji Earthquake. We get several results based on an analysis of questionnaires and the damage occurred by Ji-ji Earthquake. The rate of casualty and damage index for residential houses increase in areas in the hanging wall of the Chelungpu Fault. The questionnaire seismic intensity shows a good agreement with the instnimental seismic intensity calculated by recorded seismograms when questions related to human emotions are neglected.

13. Takada S., **Ivanov R.**, B-J. Shih, W. Chen, Specialized shell-DEM method for dynamic failure analysis of steel pipelines crossing faults, Proceedings: Second Japan-Taiwan workshop on lifeline performance and disaster mitigation, Japan, 2002, pp. 33-40

A specialised DEM method for the failure analysis of shell structures is presented. Hereby, a shell is represented by an equivalent lattice. The in-plane stiffness of shells is represented by a lattice of energy equivalent normal springs, and the bending stiffness of walls is represented by bending springs. The ability of the method to simulate highly non-linear situations is demonstrated by an analysis of a cylinder pinched perpendicularly to its axis by a force couple. A case study was carried out on a pipe in the Fengyuan region in Taiwan that sustained damage during the Chi-Chi Earthquake.

14. **Ivanov R.**, Hozumi M., Seismic behaviour of the superstructure of a multi-span simply supported bridge with rubber bearings and cable restrainers, Proceedings: 4th China-Japan-USA trilateral symposium on lifeline earthquake engineering, China, 2002, pp. 45-50

In this paper, the magnitude of the force arising in longitudinal cable restrainers during earthquake is investigated. The study was carried out by numerical simulation on a model a five-span simply supported bridge with rubber bearings. The forces in the cables were generally found to grossly exceed the current design value. Numerical experiments on different structural configurations indicate that reduced loose length of restrainers is beneficial in reducing both maximum and residual transversal slip although the restrainer forces in this case are larger.

15. Takada S., **Ivanov R.**, Evaluation of the potential for flying-off of gate column crowns due to vertical dynamic disturbances, 14 Symposium of the Kansai chapter of the JSCE, Japan, 2002, I-94-1 - I-94-2

Reportedly, there are witness observations indicating that during strong earthquakes objects fly off the ground reaching notable heights. Although not substantiated by hard evidence there must be some truth in such statements which renders a quantitative study on what height a body not firmly fixed to its base can reach when subject to various types of dynamic disturbances and earthquake waves in particular. In the paper we try to find causes for such behavior by numerical experiments so that if similar behavior patterns are observed during earthquake, these to be judged as the result of input ground motions similar to those we use in the numerical experiments.

16. Takada S., Hozumi M., **Ivanov R.**, Reliability of bridge cable restrainers of bridges, 57 Annual conference of the JSCE, Japan, I-816, 2002, pp. 1631- 1632

The behavior regarding the failure of the bearings and the forces arising in the cable restrainers under the impact of design earthquakes from the Japanese norms for bridge design are analyzed. After breaking of the bearings, the tension is switched off, and friction with or without sliding occurs. Two types of "instantaneous" and "delayed" restrainer activation have been identified, with the former being activated immediately after bearing failure and the latter after a number of oscillation cycles. The "instantaneous" type of activation leads to greater efforts in the restrainers. It was found that the forces in the "instantaneous" type of activation are higher at a lower coefficient of friction after bearing failure, while in the type of activation "delayed" the dependence is reversed. It was found that the forces in the restrainers are a function of the weight of the superstructure and not of the support reactions, as specified in the Japanese norms. A theoretical-empirical method for determining the force is proposed, without the need to make an analysis of the structure. It was found that the forces in the restrainers can increase significantly if the structure is exposed to the two horizontal earthquake components simultaneously.

17. Takada S., **Ivanov R.**, Hozumi M., Method for evaluation of the force in longitudinal cable seismic restrainers, 11 Earthquake engineering symposium, Japan, 2002, pp. 1667-1672

In this paper, the magnitude of the force arising in longitudinal cable restrainers during earthquake is investigated. The study was carried out by numerical simulation on two models; one of a five-span continuous bridge and another of a single span bridge, both on rubber bearings. The cumulative force arising in the restrainers after failure of the bearings was found to grossly exceed the current design guidance value. In absolute terms, the maximum force in the restrainers was in the order of the weight of the upper structure for the continuous bridge, and three times the weight for the single span bridge. A practical method based on energy conservation for computing the force is proposed.

18. Takada S., **Ivanov R.**, Numerical Simulation of the Behaviour of Buried Jointed Pipelines under Extremely Large Fault Displacements, Proceedings: TCLEE 2003 Conference, Long Beach, USA, 2003, pp. 717-726

A comprehensive numerical method for limit state simulation of buried jointed pipelines is presented. The pipe body is modelled by line elements and plastic deformation within it considered by plastic hinges. The basic mechanical properties of all common pipe joints e.g. stiffening in compression, detachment in tension, fracture in bending can also be considered. Soil-pipe interaction is modelled by elasto-plastic direct and drag springs. The method is capable of tracing the behaviour of pipelines until and after failure of the pipe body and detachment at joints, thus allowing the physical damage to a pipe network to be better estimated. The method is three-dimensional, thus allowing the interaction of pipeline segments running in different directions to be evaluated as well. The solution algorithm is based on the direct integration of uncoupled equations of motion, which ensures that the behaviour of a pipeline can be investigated for any magnitude of ground displacements, revealing the whole spectrum of events occurring in the pipe-soil system with the increase of earthquake induced ground displacements: elastic deformations, plastic deformations in the soil, plastic deformations in the pipe body, rupture and detachment at joints, failure and rupture within the pipe body. The method is implemented into a computer program and several trial runs are presented.

19. Takada S., Hozumi M., **Ivanov R.**, Numerical study on the effectiveness of cable restrainers in reducing post-failure slip at the bearings of simply supported bridges, Proceedings of the Graduate School, Kobe University, Japan, 2003, pp. 15-23

In this paper, the magnitude of the force arising in longitudinal cable restrainers during earthquake is investigated in order to identify well performing structural configurations. The study was carried out by numerical simulation on a model of a five-span simply supported bridge with rubber bearings. The forces in the cables were generally found to grossly exceed the current design value. The structural configurations tested in this paper were based on the assumption of a constant total restrainer gap and identical girder-to-girder and girder-to-abutment gaps. The shares of abutment-to-girder and girder-to-girder restrainer gaps were then varied. It was found that a configuration in which the girder gaps are at the upper practical design limit and the intermediate restrainer gaps are as small as possible performs the best in terms of all studied criteria, i.e. average force arising in the restrainers, average collision force and average maximum lateral slip. The lateral displacements in all analyses were much smaller than the theoretical potential for free slip. This can be attributed to the random nature of the earthquake motion and the effect of post-failure friction.

20. **Ivanov R.**, Takada S., Analysis of jointed pipelines crossing faults by a purpose-made specialized program, Report of the Research Center for Urban Safety and Security; Kobe University, Japan, 2003, pp. 203-212

A comprehensive numerical method for limit state simulation of buried jointed pipelines is presented. The pipe body is modelled by line elements and plastic deformation within it considered by plastic hinges. The basic mechanical properties of all common pipe joints e.g. stiffening in compression, detachment in tension, fracture in bending can also be considered. Soil-pipe interaction is modelled by elasto-plastic direct and drag springs. A parametric study was carried out on a ductile iron gas pipe with anti-seismic mechanical joints. Fragility curves for joint failure depending on fault crossing location and angle were derived and multiple joint failure scenarios identified. Fragility curves for the failure of the pipe body in bending were also derived.

21. **Ivanov R.**, Takada S., Sakai A., Performance of pipe bridges subjected to seismic hazards, Memoirs of the Construction Engineering Research Institute Foundation, Japan, No. 45, 2003, pp. 171-180

Pipe bridges are an integral part of the water distribution pipeline network in a modern city. Therefore, their seismic performance is crucial to the seismic performance of the whole network in general. However, the structural characteristics of pipe bridges are quite different from those of a pipeline, because they are above ground; and still different from those of a bridge because of their light weight. In this paper we study the performance of a model pipe bridge subjected to two relevant seismic hazards, namely ground shaking and liquefaction of surrounding soil. The major findings of the study are that ground shaking is not likely to cause damage, whereas liquefaction around the supports can be potentially damaging unless the supports are of pile foundation type.

22. Takada S., **Ivanov R.**, Morita N., Large deformation analysis of jointed pipelines by the DEM (in Japanese), Memoirs of the Construction Engineering Research Institute Foundation, Japan, No. 45, 2003, pp. 111-122

The paper examines the behavior of underground PVC pipelines with mechanical joints crossed by a fault. The used calculation method and its program realization are clarified. A method for changing the directions of the springs taking into account the soil-pipeline interaction is proposed, for performing a geometric nonlinear analysis. Verification of the method was performed as analytical results were compared with the results of a field experiment. A parametric analysis was performed, the varied parameters being the location of the fault line and the angle of intersection with the fault. The bearing capacity curves for the different combinations of parameters as well as the failure mechanisms (type and sequence) are obtained.

23. Takada S., Torii N., Katagiri S., Shimoda J., Tanaka H., **Ivanov R.**, Report on field damage investigation during the July 26, 2003 Miyagi-ken Hokubu Earthquakes (in Japanese), Memoirs of the Construction Engineering Research Institute Foundation, Japan, No. 45, 2003, pp. 245-264

The article examines and describes all aspects related to the Miyagi-ken Hokubu earthquake in northern Japan; landscape of the area, humidity of the earth base, mechanism of fault movement caused by the earthquake, aftershocks, geographical distribution of intensity in the affected area, specifics of earth movements (in the time and frequency domains), damages - of residential buildings (slight and severe), pipelines, failure of the ground base, liquefaction of the soil, technology of rescue operations. Much of the data was obtained from a visit by the authors of the area around the epicenter of the earthquake. Despite the observed peak accelerations of about 0.4g, the damage is relatively small. This is due to the high fundamental frequency of the earth's vibrations - between 5Hz and 10Hz. Some accelerometers had recorded oscillations with peak accelerations of about 2g. Their reliability or the reason for their appearance should be further investigated. Damage to the building stock was concentrated in old residential buildings as well as traditional masonry buildings. However, some public buildings were also damaged, which is a cause for concern. The damages of the roads and the earth embankments are big. Rock landslides are also observed. Power to more than 100,000 households was cut off, but was restored within 12 hours.

24. Takada S., **Ivanov R.**, Kato S., Ueno J., Damage investigation report on May 26, 2003 Sanriku-minami earthquake (in Japanese), Memoirs of the Construction Engineering Research Institute Foundation, Japan, No. 45, 2003, pp. 227-244

The article examines and describes all aspects related to the Sanriku-minami earthquake in northern Japan; landscape of the area, humidity of the earth base, mechanism of fault movement caused by the earthquake, aftershocks, geographical distribution of intensity in the affected area, specifics of earth movements (in the time and frequency domains), damages - of residential buildings (slight and severe), pipelines, failure of the ground base, liquefaction of the soil, technology of rescue operations. The earthquake was caused by a local rupture of a tectonic plate and is very deep (71 km). As a result, there is a high intensity in a large area. Although in many places the intensity was 6 on the Japanese scale, the damage was small. The damages of the roads and the earth embankments are big. Rock landslides are also observed, and in port cities

liquefaction of the soil and sand eruptions. Compared to the strength of the earthquake, the damage to infrastructure was small. The coordination of the responsible departments in the restoration of the electricity supply, gas supply, water supply and restoration of the telecommunications was not good.

25. **Ivanov R.**, Takada S., Assessment of the vulnerability of jointed D.I.P. crossing active faults, Proceedings: 27th JSCE Earthquake Engineering Symposium, Japan; 2003, on CD

A numerical assessment of the vulnerability of underground jointed ductile iron pipelines (D.I.P.) subjected to fault displacements is performed. An outline of the capabilities of the in-house specialized program used in the analyses is given. The major parameters affecting pipeline behaviour, namely pipe diameter, fault crossing location and fault crossing angle have been studied and vulnerability charts produced. In addition, the possibility of failure at multiple locations, and patterns of multiple failures are identified. The results of this research provide useful guidance to locating failed pipes after an earthquake, and defining the magnitude and scope of failure at a particular location.

26. **Ivanov R.**, Takada S., Behaviour of buried pipelines crossing faults – analysis aspects, Japan-Turkey workshop on gas lifeline performance and disaster mitigation, 2003, Japan, pp. 27-33

A shell-like DEM modelling strategy that is computationally inexpensive compared to the typical DEM modelling approach was introduced. The analyses performed on pipes crossing active faults showed that local buckling should be avoided if we want to achieve the best performance from a pipe. Whereas failure cannot be avoided when excessive fault motion occurs, the ultimate differential displacement a pipe can sustain without damage can be increased significantly by using pipes of lower D/t when faults are crossed. In any case, an optimal value for the ratio D/t should be sought. Fault motions with direction similar to the direction of pipe axis were confirmed to be most damaging. Pipe-soil interaction influences the behaviour in a negative way leading to strain localisation and hence to faster failure.
A comprehensive numerical method for limit state simulation of buried jointed pipelines was developed. The method is capable of tracing the behaviour of pipelines until and after failure of the pipe body and detachment at joints, thus allowing the physical damage to a pipe network to be better estimated. In order to minimize the computation time, the pipe body is modelled by line elements. The basic mechanical properties of all common pipe joints e.g. stiffening in compression, detachment in tension, fracture in bending can be considered.

27. **Ivanov R.**, Takada S., Morita N., Analytical assessment of the vulnerability of underground jointed PVC pipelines to fault displacements, Proceedings: 13th World Conference on Earthquake Engineering, Canada; 2004, on CD

A comprehensive numerical method for assessing the total damage of buried pipelines was developed. The pipe body is modelled by line elements, and plastic deformation within it considered by plastic hinges. Experimental joint behaviour data is used without any simplifying assumptions in order to make the overall pipeline response as realistic as possible. Soil-pipe interaction is modelled by elasto-plastic normal and drag soil springs. The performance of the program is verified against test data. The influence of the main parameters affecting pipeline behaviour, namely pipe diameter, stiffness of surrounding soil, fault crossing location and fault crossing angle have been studied, vulnerability charts for common pipe diameters produced, and patterns of failure identified. Simplified equations for predicting the fault slip at failure are derived. It was found that for fault crossing angles in the ranges 30° to 75° and 120° to 150° the failure modes are exclusively joint pull-out and joint compression. For these ranges the influence of soil stiffness and fault crossing location is negligibly small. The failure appears to depend simply on the amount of pull-out or compression allowance of the particular joint. On the other hand, for the range 75° to 120° the failure mode can vary from joint pull-out (up to 90°), through bending failure of the pipe body or joint (90° to 120°)

to joint compression failure (120°), and the failure slip in this range can be between two an ten times as large as the failure slip at crossing angles 30° or 150°.

29. **Ivanov R.**, Design of gas pipelines in earthquake regions – the Japanese experience and possible applications in Bulgaria (in Bulgarian), Proceedings: DCB 2004; Design and construction of buldings and facilities, Bulgaria, 2004, pp. 118-124

The design method for gas pipelines in earthquake regions in Japan is outlined. The quality requirements to materials, welding, as well as the design philosophy, the type of earthquake effects that must be considered, and the way of determining them are explained. The assumptions and equations for calculating ground displacements and strains, as well as the equations for the resulting strains in the pipelines are explained. The methods for considering soil-pipe interaction are also outlined, followed by the treatment of special cases such as non-uniform soil, curved segments and bends. In view of the intensive gasification currently under way in Bulgaria, the necessity of carrying-out earthquake resistant design, and the relevance of Japanese experience to local conditions have been analysed.

30. **Ivanov R.**, Experimental determination of the dynamic characteristics of buildings using ambient vibration records. (in Bulgarian), Proceedings: International conference VSU 2005, Sofia, Bulgaria, 2005, pp. I-36 – I-41

Dynamic identification through ambient vibration processing is proposed for cast-in-situ, medium-height RC buildings. A short description of the signal processing methods used is given, followed by an example of the dynamic identification of a five-storey building; block 4 of the BAS. Four natural frequencies and the corresponding mode shapes have been identified. The corresponding modal damping ratios have also been computed. The method was found to work well on this particular type of buildings.

31. **Ivanov R.**, Kostov M., Hadjiyski K., Simeonov S. Experimental determination of the dynamic characteristics of precast RC concrete buildings (in Bulgarian), 2005, Building Journal, Issue 5, 2005, Sofia, Bulgaria, pp. 6-12

Dynamic identification through ambient vibration processing is applied for two typical single-storey precast RC buildings. A short description of the signal processing methods used is given, followed by experiment description and results for the two buildings. The natural frequencies and the corresponding mode shapes up to 10Hz have been identified. The corresponding modal damping ratios have also been computed. The method was found to work well on this type of buildings. The results provide important background for advanced seismic analysis of precast RC buildings.

32. Kuwata Y., Takada S., **Ivanov R.**, Estimation of allowable fault displacements for pipelines and countermeasures, Proceedings: Pipelenes 2005, ASCE, Reston, USA, 2005, pp. 674-685

The paper addresses the behavior of polyvinyl chloride and ductile iron pipeline due to fault displacement by Discrete Element Method (DEM) and an estimation method of allowable fault displacement. In modeling of pipe and joint, nonlinear material properties and nonlinear joint characteristics (allowing detachment at joint) are considered. Under the set of various conditions with pipe material, pipe diameter, crossing location and crossing angle, the allowable fault displacement to reach failure of the pipe is numerically simulated. The results show that narrow angle between fault line and pipeline provides unsafe condition for pipe. Furthermore, a simplified formula to estimate allowable fault displacement is proposed considering joint failures due to axial forces. Estimates from the simplified formula agree with simulation results. Finally, measures of installing pipeline with high performance joint are considered and these behaviors are discussed.

33. Simeonov S., Hadjiyski K., **Ivanov R.**, The capabilities of the renovated national strong ground motion network, Proceedings: 10th Jubilee NC on TAM Conference, Volume II, Varna, Bulgaria, 2005, pp. 309-314

The National Strong Ground Motion Network (SMN) provides information about and related to the seismicity of Bulgaria, targeting earthquake risk reduction activities in the country. It was established in 1979 at the CLSMEE, equipped with analogue accelerographs. In 2004 the Network was reconsidered, reflecting the current trends in the development of similar systems and supplied with new digital equipment. The purpose, main characteristics and capabilities of the new autonomous digital accelerographs model ETNA and the 12-channel seismic station K2 are presented. The possibilities of the new specialised software for processing and analysis of signals are demonstrated. The main objectives for seismic instrumentation of structures are discussed. The special issue of ambient response testing for modal identification of buildings and structures, planed for future permanent instrumentation and seismic monitoring, is also treated and illustrated in practice. In conclusion, the importance of the SMN for the contemporary "information society" and the need for increasing its density is discussed.

34. Takada S., **Ivanov R.**, Kuwata Y., Analysis of a pipeline failure due to landslide during the Niigata-Chuetsu earthquake. (in Japanese), 24th Symposium of the Japanese Society on Natural Disasters, Sendai, Japan, 2005, pp. 1-2

In the 2004 Niigata Chuetsu Earthquake, a large-scale road collapse occurred on road 24. Ductile cast iron pipe buried in parallel along the road, and the polyethylene pipes were damaged. Even in the Hyogo-ken Nanbu Earthquake, there were no cases of gas polyethylene pipe being damaged even with a large-scale landslide. The authors had the opportunity to investigate the water pipe damage as a research team of the Ministry of Health, Labor and Welfare. A second detailed survey was conducted at the same site. In the text, the results of the survey and DEM analysis simulation for damage were compared and good agreement was demonstrated.

35. **Ivanov R.**, A simple model for vehicle-structure interaction, Proceedings: International conference VSU 2006, Sofia, Bulgaria, 2006, pp. I-224 – I-228

There are many situations where detailed knowledge is needed on the effects caused by the interaction between moving vehicles and the supporting structure. Examples of such effects are the transient stress developing in the structure and in the vehicle, important for fatigue design; the influence earthquakes may have on the motion of vehicles, important for assessing driver safety, etc. A simple model for numerical modelling of vehicle-structure interaction is proposed and its performance demonstrated. The key feature of the model is the explicit representation of the wheel-road surface contact problem, whereby the wheel modelled as a rotating rigid body contacts the road surface modelled as a plane constrained to the structure. The stiffness of contact reflects the elastic properties of the wheels. The wheels are connected to the vehicle chassis (a rigid body) by beam elements reflecting the elastic properties of the suspension. The vehicle is set to motion by applying a rotary moment to the tyres. The forces arising at a contact point are transferred to both the vehicle and the structure; thus dynamic equilibrium throughout the explicit time stepping solution is maintained. Time-histories of internal forces of the structure, and accelerations inside the vehicle for different input settings are presented to demonstrate the capabilities of the model.

36. **Ivanov R.**, The response of unanchored bodies subjected to 3-D seismic motion, Proceedings: DCB 2006; Design and construction of buildings and facilities, Bulgaria, 2006, pp. 326-331

In this paper the response of unanchored rigid bodies subjected to base shaking is investigated. The paper starts with a review on past research on the subject including analysis methods. A discrete element method

for the analysis of a single rigid body placed on a base plane is formulated and implemented in a computer program. A verification run was done on a body enclosed by a floor and walls. Collisions with multiple planes were successfully detected. All possible modes of motion occurred during the simulation in a smooth succession: rest, rocking, rocking-sliding and sliding. In addition, one more mode – "walking" could be identified for this 3-D case, whereas the body moves forward while rocking and turning around a vertical axis. Then the sliding response of a body was investigated in more detail using the number of ground motion components, the coefficient of friction and the PGA of the record as parameters.

37. Simeonov S., Hadjiyski K., **Ivanov R.**, Full scale testing and dynamic identification of RC residential buildings. (in Bulgarian), Proceedings: DCB 2006; Design and construction of buldings and facilities, Bulgaria, 2006, pp. 320-325

Dynamic identification through ambient vibration processing is carried out for two RC residential buildings. A short explanation of the signal processing methodology is followed by experiment description and the results for the two buildings are submitted. The first three natural frequencies and the corresponding mode shapes have been identified. The modal damping ratios have also been computed respectively. The methods used were found to work well on this type of buildings. The compiled data provide an adequate background for advanced seismic analysis of that type of RC buildings.

39. Tanaka Y., Takada S., Kuwata Y., **Ivanov R.**, Failure mechanisms of water PE pipelines subjected to landslides, 18 Symposium of the Kansai chapter of the JSCE, Japan, 2006, I-2

In the 2004 Niigata Chuetsu Earthquake, a large-scale road collapse occurred on road 24. Ductile cast iron pipe buried in parallel along the road, and the polyethylene pipes were damaged. The purpose of this study is to clarify the fracture mechanism of the pipeline by simulating the fracture phenomenon of the pipeline by numerical analysis. Also, we examined the amount of ground flow leading to the breakage of different pipelines. Properties of DIP joint were used as prescribed by the manufacturer, and the properties of the polyethylene pipe connected were obtained from test results. Two plausible loading patterns were used, and the axial forces and bending moments in the pipes were obtained. Since the forced displacement is tilted with respect to the pipeline axis, tensile force emerges on the upstream side of the pipeline and bending dominates in the downstream side. It was found that the tensile force is leading the collapse mechanism. If the diameter were 150 mm, the rupture would not have occurred.

40. Shibata Y., Takada S., Kuwata Y., **Ivanov R.**, Relation between slip and overturning behaviour of furniture during earthquake and earthquake strength, 18 Symposium of the Kansai chapter of the JSCE, Japan, 2006, I-12

Preventing furniture from falling over in the room during an earthquake will reduce human damage. It is important to clarify the relationship between the tilting behavior and the seismic intensity. Therefore, in this study, we use the Discrete Element Method (DEM). We used it to simulate the behavior of furniture during an earthquake, and verified the amount of slippage of the rigid body and the overturning of the rigid body from the analysis results. Furthermore, we compared the results of the analysis with the questionnaire on the behavior of furniture.

41. **Ivanov R.**, DE–FE method for simulation of the behaviour of furniture during earthquake, 2006, 61 Annual conference of the JSCE, Japan, I-421

A hybrid DE-FE for collapse analysis of furniture was formulated, its accuracy tested, and its ability to simulate the behavior of furniture during earthquake demonstrated. The use of high-performance finite

elements allows the accurate modeling of the stress-strain state in the furniture at any time, allowing a more accurate estimate of the response at collision to be made; wave propagation in the model is considered. At the same time, the DE algorithm allows to solution to be done without assembling a stiffness matrix, and the contact problem is easily handled. Special provisions need not be made for geometrical nonlinearity either.

42. Shibata Y., Takada S., Kuwata Y., **Ivanov R.**, Furniture overturning analysis considering collision with walls, 61 Annual conference of the JSCE, Japan, 2006, I-293

In this study, we examine the behavior of a chest of drawers installed adjacent to a wall. A time-history seismic response analysis was performed. The chest of drawers is modelled as a rigid rectangular parallelepiped. The numerical analysis is based on the Discrete Element Method (DEM). An improved 3D analysis device that can determine the contact between a surface and an element. Three cases were considered; 1. the chest is free standing (away from walls), 2. the chest is next to a wall, 3 the chest is 5cm away from a wall. The collapse mechanism as a function of the position of the chest and the PGA of the input motion was investigated, and case 3 was identified as the safest one.

43. Kuwata Y., Takada S., **Ivanov R.**, DEM Response Analysis of Buried Pipelines Crossing Faults and Proposal for a Simplified Method to Estimate Allowable Fault Displacements, Journal of Seismology and Earthquake Engineering, Iran, Vol. 8, No. 4, 2007, pp. 195-202

This paper investigates the behavior of polyvinyl chloride and ductile iron pipelines in relation to surface fault displacements using the Discrete Element Method (DEM) and proposes a method to estimate the allowable fault displacements. When modeling pipes and joints, the nonlinear material properties and joint characteristics (allowing detachment at the joints) are considered. Under a given set of various conditions with respect to pipe material, pipe diameter, crossing location and crossing angle, the allowable fault displacement to reach failure of the pipe is numerically simulated. The results show that a narrow angle between the fault line and the pipeline presents unsafe condition for the pipeline behavior. Furthermore, a simplified formula to estimate the allowable fault displacement is proposed, which considers joint failures due to axial forces. Estimated results achieved by this formula agree with the results obtained by numerical simulation. Finally, measures for installing pipelines with high performance joints are considered and discussed.

44. **Ivanov R.**, Computer program for structural analysis of embedded retaining walls, Proceedings: Sofia Metro Jubilee Conference, Sofia, Bulgaria, 2008, pp. 44-50

Embedded retaining walls are often used in metro construction. Their supports during the construction process are temporary structures, so their economic and yet safe design is an important issue. The program described in this paper computes the internal forces and displacements of embedded walls and their supports if any, considering the sequence of stages in the construction process, the nonlinearity of soil, and all possible shifts between active, passive and at-rest soil pressure as digging proceeds. The results computed by the program are verified against results from field measurements, and the agreement is found to be very good.

46. Partov D., **Ivanov R.**, Design and Construction of the Orthotropic Steel Deck Bridge in Elin Pelin, Bulgaria, 2008, International Orthotropic Bridge Conference, Section - Design, 25-29.08.2008, Sacramento, California, USA, ASCE, (CD), pp. 116-124

The paper presents the 300m long, Gerber type orthotropic steel deck bridge in the town of Elin Pelin (Bulgaria). Details on the bidding procedure, such as participants, bidding requirements are described in detail. Following is an account on the abilities of the contractor to provide the service required, including a

description of the modular structures they specialize in. Next, the particular structure proposed is described in detail, including structural action and detailed design of the orthotropic deck, all principal and secondary members. Finally, a brief note is given on the seismic design, followed by the technical and economical constraints imposed on the contractor by the client.

81. Partov D., **Ivanov R.**, Dinev D., The history of the first orthotropic bridge in Bulgaria, Proceedings: Recent Progress in Steel and Composite Structures – Gizejowski et al. (Eds) © Taylor & Francis Group, London, 2016, pp. 271-277

The paper presents the rehabilitation project for the movable bridge in Varna, following its failure in 1975. The existing old bridge is designed and built by the "MAN" company in 1939. In 1975 the movable part and one from the stationary parts of the bridge was completely destroyed by a ship accident. The reconstruction included installing new superstructure in two bays, while the original structure in the third bay was kept in place. The bridge is a 3-span steel structure with a total length of 80.34 m. The movable and one stationary parts were designed as simply supported bridge structure with an orthotropic deck. The movable bridge consists of two identical Warren trusses with spans of 31.62 m. The stationary parts were designed as simply supported bridge with an orthotropic deck also. The superstructure consists of two main girders are 2.80 m deep with a distance between them of 8.00 m.

88. A. D. Kaneva, I. Z. Paskaleva, **R. I. Ivanov**, I. Y. Ivanchev, A. N. Gorolomov (2019) SEISMIC VULNERABILITY ASSESSMENT AND PIPE DAMAGE DATA ANALYSIS FOR THE 2012 PERNIK EARTHQUAKE IN BULGARIA ICONHIC 2nd International Conference on Natural Hazards & Infrastructure 23-26 June, 2019, Chania, Greece.

An earthquake of magnitude M_w 5.6 hit Western Bulgaria, on 22th May 2012, 25 km SW of the Bulgarian capital, Sofia and near Pernik, the closest city to the epicentre. In the General Plan of the Municipality of Pernik, among other problems of the aged water and sewer systems, it is mentioned that probably this earthquake caused displacement of the concrete pipes that led to plugging of a siphon of the city sewer system. However, the effect of this earthquake on the water and sewer pipelines in Pernik remains unknown. The aim of this research work is to analyse the likelihood of occurrence of damages, breaks or leaks in the water and sewer systems due to the earthquake of 2012, based on public data for the pipelines and assessment of the effects of the earthquake, in terms of PGV and soil strain. A detailed study of the pipe damages in the systems before and after the earthquake is carried out on the basis of damage/repair data collected daily by the Water Supply and Sewerage Company in Pernik.

92. **Ivanov R. I**. Seismic behaviour of brickwork chimneys in buildings. IOP Conference Series: Materials Science and Engineering, 951, IOP Publishing, 2020, ISSN:1757-8981, DOI:doi:10.1088/1757-899X/951/1/012017, pp. 1-6

The construction of chimneys of solid bricks in buildings with sloped roofs was commonplace in Bulgaria for almost a century. The collapse of a chimney during an earthquake could potentially lead to damages greatly exceeding the loss of the chimney itself, e.g. partial damage to the roof tiling and leaks, as well as material damage, injury or loss of life due to debris fall. A FEM model was created, in which the storeys of the building are represented in a generalised way, while the chimney is modelled explicitly as a cantilever supported at roof level. The internal forces in chimneys with heights ranging from 0.5 m to 2.0 m, belonging to buildings with height ranging from two to seven storeys were computed. Acceleration records from real earthquakes acting at the base of the building with varying peak ground acceleration and predominant period were used for input loading. The maximum tensile stresses at the bed joints were computed and were compared to the typical tensile strength of the mortars used for chimney construction, to assess the possibility of collapse. A simple, low-tech method for upgrading of existing chimneys by applying a coat of cement-based plaster with embedded fiberglass mesh is proposed.

93. Zhelyazov T., **Ivanov R.** Numerical investigation of the mechanical behaviour of a structural element containing a self-healing agent. IOP Conference Series: Materials Science and Engineering, 1002, IOP Publishing, 2020, ISSN:1757-8981, DOI:10.1088/1757-899X/1002/1/012015, pp. 1-7

This paper presents a virtual experiment on the behaviour of a self-healing material from the family of cement-based composites, that contains a healing agent. A numerical model of a specimen made of a cement-based material, and containing a healing agent is subjected to the loading configuration of the four-point bending test, whereby the forces are applied in a quasi-static way. The response of the healed specimen is compared to the response of a specimen that doesn't contain a healing agent. For the specimen that contains a healing agent, homogenization techniques are used to determine the characteristics of the equivalent material (cement-based composite / healing agent) in zones where damage and macro-cracking have occurred, i.e., zones in which the healing agent has been activated. The main result of this contribution is the formulation and validation of a numerical simulation approach suitable for modelling the mechanical behaviour of self-healing cement-based composites.

96. **Ivanov, R.**. Computation of source-to-site distance distributions for seismic hazard analysis. 35th International Conference on Information Technologies, InfoTech 2021 - Proceedings, Institute of Electrical and Electronics Engineers Inc. (IEEE), 2021, ISBN:978-166540324-5, DOI:10.1109/InfoTech52438.2021.9548120, pp. 19-22

An algorithm for computation of source-to-site distance distributions is proposed, implemented in VBA and verified. It consists of two stages: first a point cloud is generated inside the source area, and then the distribution of distances from each point to the site is computed. The distribution is expressed as a histogram for user-defined ranges between the minimum and the maximum distance.

97. Zhelyazov, T., **Ivanov, R.**. Modeling of the behaviour of concrete elements containing a self-healing agent. IABSE Congress Ghent 2021: Structural Engineering for Future Societal Needs, IABSE, 2021, pp. 79-84

This contribution focuses on the numerical modelling and simulation of the mechanical behaviour of structural elements containing a self-healing agent. Specifically, the finite element modelling of the mechanical response of plain concrete structural element, containing a healing agent and subject to various loading conditions is discussed. A customized numerical procedure designed to implement the Damage Mechanics-based constitutive relation for concrete into a general-purpose finite element code is developed. The procedure comprises algorithms for evaluation of the volume of newly-formed cracks, the recovery of stiffness of the structural element due to crack closure, the initiation of healing and its effect on the overall response of the structural element. The procedure is demonstrated by simulations of a concrete cylinder subjected to compression and torsion.

98. Zhelyazov, T., **Ivanov, R.**. Numerical simulation of cracking in concrete using damage mechanics. IABSE Congress, Christchurch 2020: Resilient Technologies for Sustainable Infrastructure - Proceedings, IABSE, 2021, ISBN:978-385748170-3, pp. 881-889

Damage Mechanics is employed to simulate the crack initiation and propagation in concrete structural elements. To this end, the stress-strain relationship for concrete is modified by introducing a damage variable which affects the elasticity tensor. The damage-based constitutive relationship defined for concrete is integrated into a general-purpose finite element code. The damage accumulated in each finite element is quantified throughout the loading history. Finite elements in which a critical value of the damage variable is reached are deactivated. The volume of cracks can also be approximately evaluated. The relative amount of

cracks is considered by the authors to be an important characteristic of the material in the context of smart, self-healing concrete. It provides valuable information for the design of a smart structural element, namely in optimizing the amount and pattern of placement of the healing agent.

103. Popova M., Oynakov E., Solakov D., Aleksandrova I., Dragomirov D., **Ivanov R.**. Experimental Evaluation of the Dynamical Parameters f0 and A0 Using the Method HVSR. 11th Congress of the Balkan Geophysical Society, 10-14 October, Bucharest, 2021, pp. 1-5

Microzonation is one of the main tasks in the analysis of the seismic hazard, seismic risk and the following political planning to lower damage from earthquakes. For the purposes of microzonation first the dynamical capabilities of the soil have to be determined. This information can be attained by invasive and time-consuming methods. Extra problems arise in a city area where the measurements are affected by industrial noise and traffic. It is necessary the development of quick, effective and non-invasive methods aimed at the evaluation of the seismic characteristic of the upper layers of Earth`s crust. Passive seismic methods depend on the registration and analysis of microseismic noise from a natural, as well as from anthropogenic origin, the latter being very common in cities. In this research for the purpose of evaluating the resonance effects by seismic waves is used the method of Horizontal to Vertical Spectral Ratio (HVSR) of microseismic noise, which can evaluate the relation between soil/construction. For areas with potentially high seismic risk, like the one that is observed in the area of Sofia, this method is suitable. This method is suitable for a city area because it does not need sources of artificial origin.

Prepared: ……
/Dr. R. Ivanov/