and stress limitations, as explicit functions of the design variables.

The material costs of reinforced concrete frames are dependent on dimensions, reinforcement ratios and formworks of structural elements, and the unit costs of concrete, steel reinforcement and formwork. Whilst trying to optimize the cost of a structure, certain conditions have to be met so that the equilibriums of the sections are maintained and the requirements of relevant standards are satisfied. Although various structural optimization methods are developed, the minimum cost of reinforced concrete frames is difficult to achieve using existing design methods. There are an infinite number of alternative dimensions and reinforcement ratios for structural elements that can yield a similar force or moment of resistance. These elements are often the major components in reinforced concrete skeletal structures, and hence their economical design requires consideration as it is an important factor in achieving the overall cost reduction of a structure.

In this study, the application of the consistent approximation (CONAP) method is presented for optimum design of reinforced concrete moment resisting frames (RCMRFs). For this purpose, design of the RCMRFs is formulated as an optimization problem. Design variables are the dimensions of concrete sections and reinforcement areas. The objective function is the total cost of the frame which includes the cost of concrete, formwork and reinforcing steel for individual members of the frame. Design constraints are defined based on the requirements of design code requirements for concrete constructions. In the optimum design model, the objective function and design constraints are explicitly formulated using the CONAP concept and the primary optimization problem is replaced with a sequence of explicit problems. Each sub-problem is first generated based on the analysis and sensitivity analysis results Also, and then is efficiently solved by using sequential quadratic programming (SQP) method. The proposed method is demonstrated through a design example and the optimum results are compared with those in the available literature. It is shown that the proposed method can be easily applied to obtain rational, reliable, economical and practical designs for RCMRFs. Also, it is shown that the proposed algorithm is converged in just a few iterations.

**Key Words:** Structural optimization, consistent approximation, sensitivity analysis, reinforced concrete frame.

## NOVEL MODEL FOR ESTIMATING THE COST OF RISK IN ASSIGNATION CONCESSION CONTRACTS USING MONTE CARLO SIMULATION METHOD

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**Abstract**

According to the development strategy, private sector participation in implementing and developing infrastructure projects led to further financing and increase the productivity of the economy. In the past, many developing countries were followed heavy investment plans to strengthen the infrastructure systems. These investments were aimed at reducing the external costs and the custom duties. The investment plans were led by the government or the governmental organizations and their source were financed by loans. The heavy costs of subsidies had caused the income earned from investments be insufficient so that it would be impossible to pay back the loans. Implementing control plans to prevent internal and external debt rose have done severe restrictions and pressures on many countries for investment in new infrastructure projects and even maintaining the built projects.

Infrastructure development is one of the major elements of economic development in countries. In the past few decades, the infrastructure projects were financed through concession agreements. In the concession agreements, the private sector finances the project and the Return on Investment (ROI) is obtained through incomes for the franchise period. The long duration for implementing and the high amount for investing are considered as the characteristics of infrastructure projects. Therefore, estimating the cost of risk and financial analysis is one of the effective factors in the success of projects. This study presents a methodology for estimating the cost of risk by using the data from feasibility studies and probabilistic analysis by Monte Carlo method, which it has been considered as a result of inflation and the interest rate of loans. The results showed that the methodology was very effective in the financial evaluation of the tenders relating to the projects and the possibility of project failure reduced by increasing the economic stability during the construction period.

**Key Words:** Cost of risk, financing of project, concession agreement, monte carlo simulation.

wt % for Saponin) and applied voltage gradient (1 and 2 V/cm) to the oil removal from soil were investigated in the experiments. According to results, in the tests conducted with Saponin in 1 V/cm, the maximum removal rate of 18.35% was obtained in critical concentration (0.1 %), while using the SDS leads to a removal percentage equaling to 26.14 % in the highest concentration of SDS (0.3%). In addition, increasing the applied voltage gradient to 2 V/cm in the tests with critical concentration of surfactants raised the removal efficiency about 4-6%.

**Key Words:** Soil treatment, oil contamination, electrokinetic method, surfactants, SDS, saponin.

## AN INVESTIGATION ON THE EFFECT OF NEAR-FIELD PULSE-LIKE GROUND MOTIONS ON THE SEISMIC RESPONSE OF A SOIL-PILE-STRUCTURE SYSTEM

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**Abstract**

In this study, the effect of near-field ground motions pulses on the seismic response of a soil -pile-structure system is investigated. The forward directivity effect, which includes a large velocity pulse at the beginning of the velocity time history of the ground motion, is the most damaging phenomenon observed in near-field ground motions. This large amplitude medium- to long-period pulse contains most of the seismic energy from the rupture. To investigate the effect of near-field ground motions on the seismic response of a soil-pile-structure system, a three-dimensional model, consisting of the soil, pile group and the structure is used. Modeling is performed by using the ABAQUS software. The Von Wolffersdorff hypoplastic model considering the intergranular strain concept is applied for modeling of cohesionless soil (sand), and the behavior of structure is considered to be non-linear. Eight fault-normal near-field ground motion records, which were recorded on rock, are applied to the model. The results show that near-field velocity pulses have a considerable effect on the behavior of the system, and cause sudden large displacement demands on the structure and piles. Therefore, the structure undergoes large non-linear deformations, and the fundamental period of the structure elongates. It should be noted that when the elongated period of the structure is near the period of the velocity pulse, the severity of non-linear deformation increases. In addition, there are positive correlations between the PGV and PGD values of the ground motion records, and the deformation demands on the piles.

**Key Words:** Near-field ground motions, soil-pile-structure interaction, hypoplasticity, finite element method.

## OPTIMUM DESIGN OF RCMRFS USING CONSISTENT APPROXIMATION METHOD

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**Abstract**

Structural optimization is currently one of the most important topics in structural engineering and has a wide range of applicability. The objective of structural optimization is to find design variables for a structure that minimize cost and satisfy various design requirements. A large number of optimization techniques have been developed and used in structural optimization. Among optimization methods, the mathematical programming method is attractive due to its generality and rigorous theoretical basis. The main difficulty with the use of mathematical programming for structural optimization problems to which the structural form is specific is the formulation of constraints, such as displacement

solutions represented by other researchers. In the cases with multiple point sources in which no analytical solution exists, verification was carried out by numerical models. The Final graphs and statistical analysis show good agreement between the results of numerical models and the proposed solution. Also, finally, it can be concluded that the most comprehensive set of analytical solution to ADRE for different combinations of applicable boundary condition in rivers was presented in this research work.

**Key Words:** Advection-dispersion-reaction equation (adre), green's function method, boundary conditions, multiple point sources, arbitrary time pattern.

## THE EFFECTS OF THE WIDENING RATIO OF A CANYON ON THE SCATTERING OF SEISMIC WAVES

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**Abstract**
In this research, seismic wave scattering from a 3D canyon, considering the longitudinal changes of its cross section, is investigated using the parameter called as widening ratio. For this purpose three dimensional boundary element method is used and a special code in Fortran is developed to perform the seismic wave scattering analysis from arbitrary cross section canyon. Comprehensive sensitivity analysis is carried out to indicate the effects of the widening ratio on the patterns of the seismic wave's diffraction. The effects of wave characteristics including, frequency, type, direction of incident wave are investigated. The results are compared to the results of the prismatic canyon. The results indicates that the widening ratio has significant effects on the scattering pattern and therefore assuming prismatic canyon such as considered in the conventional analysis may lead to the significant errors in the estimation of seismic responses. It is shown that this effects is strongly depending on the frequency content of the seismic waves.

**Key Words:** Widening ratio, boundary element, wave scattering, site effect.

## REMOVAL OF CRUDE OIL FROM SOIL USING ENHANCED ELECTROKINETIC METHOD BY SURFACTANTS

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**Abstract**
Uncontrolled emission of different contaminants in environment, such as soil and groundwater, leads to increasing the contamination and causing risks for the ecosystem and human health. Over the last century, the oil has been one of the energy sources and the raw material for many industries. It must be mentioned that about 0.1% of its production enters the seas and oceans due to various events and pollutes the water and soil. Among the different methods of soil treatment, Electrokinetic is one of the most widely used methods, especially in the case of fine-grained soils. Due to low solubility of organic contaminants in water, such as oil, application of surfactants is necessary to improve the Electrokinetic method. Surfactants can increase the solubilization of organic compounds by reducing the surface tension and interfacial tension. So, the electroosmosis flow is the most important mechanism of pollutant transport. In this study, treatment of contaminated soils with crude oil, using enhanced Electrokinetic method by surfactants in pilot scale has been investigated. For this purpose, SDS and Saponin were used to remove the oil crude (6000 mg/Kg) from soil. Each test was conducted in cells made of Plexiglas with dimensions of 30*6*5 cm during 7 days. The effect of surfactant concentration (0.1, 0.2, and 0.3 wt % for SDS and 0.05, 0.1, and 0.2

Abstract

Effect of ground deformation on adjacent building caused by excavation is one of the main concerns in the construction of underground facilities in urban areas. The performance of soil nail walls is significantly affected due to the complex mutual interaction between its main components including the native soil, the reinforcement (nails) and the facing. Additionally, various other factors, such as the construction sequence, the installation method of nails, the connection between the nails and the facing, are also likely to influence the behavior of the soil nail walls. In practice, to study the complex soil-structure interaction and assess the performance of soil nail walls, often numerical simulations are performed. It is well established that the accuracy of numerical simulations depends significantly on the constitutive soil model used.

In the present study, excavation in soft and stiff clay using hardening soil model, softening soil model, and Mohr-Coulomb model and also in loose and dense sand using hardening soil model and Mohr-Coulomb model is simulated using the finite element software "Plaxis". According to the results, considerable dependency of deformation of ground and side wall of excavation on the selected constitutive model is obvious. Based on obtained results, Mohr-Coulomb model predicts swilling at ground surface for points around the side wall.

Hardening soil model and Mohr-Coulomb model predict maximum and minimum lateral deformations of side wall, respectively, but the deformation trends of side wall are quite different due to the two models. The modeling results of loose and dense sands show the amount of predicted swilling at the bottom of the excavation using Mohr-Coulomb model is more than hardening soil model result. In this study, the maximum and minimum amounts of swilling at bottom of the excavation for soft clay are calculated by Hardening soil model and softening soil model, respectively. The results of stiff clay show the maximum and minimum amounts of swilling at bottom of excavation and near the side wall predicted by hardening soil model and Mohr-Coulomb model, respectively, but away from the side wall, softening and hardening soil models predict maximum and minimum amount of swilling, respectively.

**Key Words:** Braced excavation, constitutive model, side wall displacement, swilling, plaxis software.

## ANALYTICAL SOLUTIONS TO ONE- AND TWO-DIMENSIONAL ADVECTION-DISPERSION-REACTION EQUATION WITH ARBITRARY SOURCE TERM TIME PATTERN USING GREEN'S FUNCTION METHOD

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Abstract

Pollutants dispersion is one of the most important issues in surface waters. The governing equation dealing with this phenomenon is the advection-dispersion-reaction (ADRE) equation. The Application of mathematical models of pollution transport in rivers is very important. Moreover, it is necessary to utilize analytical solutions for numerical verification methods. Green's function method is a powerful method for solving non-homogeneous partial differential equations analytically in one or multi-dimensional domains. In this research work, the analytical solution of ADRE (with constant velocity and dispersion coefficient) for different combinations of boundary conditions was derived in one and two dimensions for infinite, semi-infinite, and finite spatial domains in the integral form including the boundary and initial conditions and source term effects separately using Green's function method (GFM). First, the general solution to ADRE equation was determined. Therefore, the final explicit solution will depend on the existence of Green's function related to the original problem. In order to find the Green's function of each problem, a powerful tool, called "Adjoint Operator", was employed. Finally, by locating the Green's function in the general solution associated with the main boundary value problem, the final solution to ADRE equation was specified. Also, the product solution rule was used to obtain Green's functions in two-dimensional domain. Also, to accelerate the convergence of the resulting infinite series, a non-dimensional parameter was defined. As a result, the small time form of Green's function using the mathematical concept was determined. The obtained solutions were derived for multiple point sources with arbitrary time patterns. Evaluation of the derived solutions was performed using several hypothetical examples and some real data. For one- point source with simple time patterns, the evaluation was done using analytical

pirical and analytical hydraulic geometry relationships were observed in this paper. This represents the self-adjusting mechanism of alluvial channels by introducing the channel shape factor (bed width/depth ratio) and the inclusion of extremal hypotheses in the flow governing equations (continuity, flow resistance and sediment transport equations). Finally, the developed model was calibrated using the field data of the United Kingdom and Iran. Obtained results confirmed the efficiency of the proposed model in rivers with high bank stability. This is due to the fact that, based on the developed analytical model, the ratio of calculated to observed widths, in 58 gauging stations located in the UK, varies on average from 0.40 to 0.72 in rivers with sparse and dense vegetation, respectively.

**Key Words:** Hydraulic geometry, analytical model, extremal hypotheses.

## FUNCTIONALIZED CHITOSAN NANOPARTICLES BY CITRIC ACID FOR ADSORPTIVE OF CHROMIUM (VI)

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**Abstract**

In the present study, carboxylated chitosan nano-particals grafted by citric acid was synthesized and used to remove Cr(VI) from a synthetic solution and a real electroplating wastewater. Nano-particles are formed by reaction of the amino group of chitosan with carboxyl group of citric acid as crosslinking agent. Synthesized materials were characterized by scanning electron microscopy (SEM) and Fourier transform infrared (FTIR) and zeta meter techniques. The optimization of different adsorption parameters, such as pH of the solution in the range of 3 to 6, the initial metal ions concentration in the range of 10 to 110 mg/l, the adsorbent dose in the range of 0.5 to 3.5 g/l and at different contact time intervals, were investigated. The results indicated that the adsorption of Cr(VI) ions on the surface of the adsorbent decreased with increasing solution pH. Optimal values of pH of the solution, concentration of metal ion, adsorbent dosage and contact time were attained at 3, 70 mg/l and 3 g/l and 60 min, respectively. Under these conditions, efficiency of maximum removal was 94% for Cr (VI) at concentration of 70 mg/l in a synthetic solution and 82.27% for electroplating wastewater. The adsorption data fairly fitted to Langmuir, Freundlich, and Sips isotherms. The adsorption isotherm was better explained by the Sips rather than by the Langmuir and Freundlich model. The kinetic data of adsorption reactions and the evaluation of adsorption equilibrium parameters just in some dosages were described by pseudo-first-order equations. To calculate thermodynamic parameters of Cr(VI) adsorption, experiments were performed at temperatures of 25, 35, $45^0C$ in a batch system. Thermodynamic parameters, such as $\Delta Go$, $\Delta Ho$ and $\Delta So$, were also evaluated.
Regeneration of chitosan nano-particles was investigated and the results indicated that three cycles of adsorption-desorption for adsorbent re-use without significant loss of adsorption capacity is attainable.
The results suggest that carboxylated chitosan nano-partical can be utilized as an adsorbent for an efficient removal of hexavalent chromium from aqueous solution and electroplating wastewater.

**Key Words:** Nanoparticale, citric acid, chromium (VI), kinetics.

## THE EFFECT OF CONSTITUTIVE MODEL ON WALL DEFLECTION ANALYSIS IN DEEP EXCAVATION

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**Abstract**

Full-mechanized excavation methods of tunnel have promoted segmental lining. One of the great and permanent ground deformations is called faulting. Tunnels are at the risk of faulting due to their long length. There are few studies that examine the behavior of tunnels intersecting the fault zones although it is a continuing concern for design engineers. In the present study, a physical model of a normal and reverse fault and segmental tunnel in a centrifuge has been modeled and tested, and then the results of eight centrifuge tests have been reported. The results indicate that segmental tunnels under the effects of reverse faulting have better resistance compared to the normal faulting. Tunnel failure mechanism in the reverse faulting is longitudinal deformation due to faulting compressive force. For certain amount of PGD, in the normal faulting, a small length of tunnel is affected by fault compared to the reverse faulting. It is related to the width of shear band in the model. Comparing to the free field, the tunnel in the model causes the faulting face some changes. In the normal faulting, the faulting is brought about to be inclined toward the hanging wall and in reverse faulting toward the footwall. The results show the absence of sudden failure of segmental tunnels under normal faulting and improvement of function in response to an increase in the overburden of the tunnel. Major failure and soil collapse inside the tunnel resulted from the opening of spaces between the segmental rings at the joints. This occurred in response to the dominant tensile forces caused by normal faulting. Sinkholes caused by the loss of soil into the tunnel are likely in the normal faulting. The area of the zone affected by faulting in the tunnel decreased as the overburden increased, but the severity of damage increased in response to localization of fault displacement. Sinkhole formation upon the collapse of soil into the tunnel is likely at the ground surface. In the reverse faulting longitudinal deformations on tunnel and at the ground, were observed.

**Key Words:** Physical modeling, segmental tunnel, normal fault rupture, reverse fault, geotechnical centrifuge.

## ROLE OF EXTREMAL HYPOTHESES IN RIVERS HYDRAULIC GEOMETRY RELATIONSHIPS DERIVATION

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**Abstract**

With the advent of the new millennium, there have been many advances in engineering science, but predicting the alluvial stream response to man-made and environmental changes is still waiting for a logical and understandable method. Rivers tend to adapt to the incurred changes by their hydraulic geometry adjustment. This adaptation is done in order to carry imposed water and sediment by adjusting the width, depth, velocity and stream longitudinal profiles. Therefore, predicting the response of hydraulic geometry is a primary engineering task to manage, design and train the rivers. Hence, in this paper, according to the downstream hydraulic geometry and the fellow regime theory proposed, and the landscape of predicting the river morphological response in the civil engineering's literature, an analytical model is proposed for assessing the stable condition (static and dynamic stabilities), and downstream hydraulic geometry relationships to be applicable to the rivers with the dominant bed load were derived. For this purpose, after reviewing the previous studies in this field, a system of equations was solved without including bank stability constraint (unconstrained model) by using the analytical model. Due to the lack of the required equations to the self-adjusting mechanism of alluvial channels and solving the system, extremal hypotheses were used. The river behavior is justified in order to optimize a specific morphologic parameter based on these theories. A good agreement between the developed exponents of hydraulic geometry relationships and the results of the em-

availability in crack modeling, but there are a few problems in using standard shape functions. Meshless methods shape functions, so Discrete least square, which is used in this research, makes them more efficient with Finite element, especially in high-gradient problems. In this study, the cohesive crack theory leaving the usual numerical methods for crack behavior is investigated. In this way, doing the model conditions that do not occur crack with force out on the edges crack, and gradually become more open crack, and decrease the cohesive tension, that done zero, it means the whole crack is opening. Therefore, meshless methods use some techniques, such as visibility criterion and diffraction method, to encounter this problem. This technique is the simplest method for discontinuity modeling in meshless methods and has more compatibility with general domain discretization in meshless methods. Through engineering problems, the domain of the problem may contain nonconvex boundaries, particularly the fractured ones having discontinuous displacement fields. In such conditions, the shape functions associated with particles, whose supports intersect with the discontinuity, should be modified. One of these criteria is the visibility. In this approach, if the assumed light beam meets the discontinuity line, the shape function after the barrier will be cut. Therefore, discontinuity is applied to the geometry. In other words, the shape function of the particles, which prevents the crack or discontinuity from reaching the light beam, will be modified to amount to a zero.
In this study, Cohesive Crack Theory is investigated for modeling and simulating crack behavior in DLS meshless method. This method gradually decreases the resistance of the cracked area to simulate splitting of the material. Finally, the high efficiency and accuracy of DLSM is given by comparing the DLSM results with experimental or FEM ones.

**Key Words:** Crack, discrete least squares meshless method, cohesive crack theory, visibility method.

## THE NEW RELATIONSHIPS FOR THE COMPARISON OF 2D AND 3D DEFORMATION OF A TUNNEL

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**Abstract**
To obtain the displacements of a tunnel is one of the major issues in the tunnel. In this paper, using the finite difference and finite element methods and measurements data, new relationships are presented between the 2-D and 3-D deformation of a tunnel. This comparison was performed between competent rock and jointed rock mass where different results are considerable. Empirical, numerical and analytical methods are regarded as different tools for design of tunnel. Nowadays, due to the advancement of technology, limitation on surface spaces, and political and security issues, many developed and developing countries focus on constructing underground structures for civil and military applications. Underground road and highways, tunnels, urban subway networks, power plants, nuclear waste repositories, oil reservoirs, shelters, and warehouses are structures which are rapidly under construction in different countries. It should be noted that these achievements have been made over a long time, accompanied by different problems. In order to predict the displacement of a tunnel with regard to its 2-D deformation, the new equations are proposed in this paper in 3-D case that can be employed. Due to the fact that in many numerical analyses, modeling is done in 2-D case, the relationships presented in this article can be real results. According to the results of the various analyses of intact rock mass, displacement of tunnel in 3-D is less than that in the 2-D case. But, in the jointed rock mass the displacement of tunnel in 2-D is less than that in the 3-D case. The results of this research have been verified by tunnel of Gavoshan's dam. After comparing and analyzing the results, relationships have been proposed for the coloration between 2-D and 3-D in intact rock mass and jointed rock mass. The solved examples give reasonable and acceptable results.

**Key Words:** Tunnel, displacement, numerical methods, 2D analysis, 3D analysis.

## AN INVESTIGATION OF SEGMENTAL TUNNELS BEHAVIOR UNDER NORMAL AND REVERSE FAULTING, USING GEOTECHNICAL CENTRIFUGE MODELLING

efficiency of theoretical method, finite element models were created. For this purpose, a finite element model was created based on existing experimental data. After the verification of this model with experimental data, five different finite element models were created with different embedded lengths. The results of nonlinear analysis showed that by increasing of embedded length, the flexural strength of connection was increased, and also showed that the linear theoretical method was efficient in predicting required embedded length to resist flexural strength of the steel pile.
To investigate the effect of spiral stirrup around the pile, one of the above five models was selected and finite element analysis was performed with and without surrounding spiral stirrup. Comparing the result of this analysis showed that using the spiral stirrup increased the flexural strength of pile-pile cap up to 58 percent.

**Key Words:** Integral bridge, steel pile-abutment connection, flexural strength of steel pile, embedded length of pile, spiral stirrup.

## EFFECT OF CHLORIDE IONS ON SULFATE IONS ATTACK IN DENSE CONCRETES CONTAINING NANO-CLAY PARTICLES

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**Abstract**
Sulfate attack on concrete is one of the severe environmental factor in reducing the service life of concrete structures. Laboratory studies on sulfate attack, revealed the importance of physical factors such as porosity on the process. Formation of expansive reaction products, such as ettringite and gypsum, can lead to cracking, spalling, and other damaging effects. Based on the accepted findings, a correlation exists between the C3A content in Portland cement and the susceptibility of concrete to sulfate attack. Cements of type II and V, having limited C3A content, were introduced to the moderate and severe sulfate concentrations, respectively. Nonetheless, in some cases, the use of Type V cement and even the use of zero-C3A cement may not prevent damage due to sulfate attack. These data encourage researchers to find out new materials for protecting concretes against sulfate attack. Also, chloride ions exist besides sulfate ions in seawaters. Therefore, chloride ions can affect the diffusion rate of sulfate ions in the concrete where a smaller amount of studies could be found.
As a result, in the present study, Montmorillonite nano-clay particles were substituted as cement in the range of 0.2 to 0.4 percent. Surface of nano-clay particles that negatively charged can prevent sulfate ions diffusion in the concrete. Water-cement ratio and cement content were considered 0.42 and 325 kg/m3, respectively. In the experiments, cubic specimens were considered for sulfate and combination of sulfate and chloride attacks after 28 days of moist curing. Mass loss of specimens and compressive strength changes were measured during 6 months of immersion. Results showed that the nano-clay particles increase the durability of concrete mixtures against sulfate and combination of sulfate and chloride attacks. Also chloride ions decrease the rate of sulfate ions attack. Furthermore, the mixture containing 0.3% of nano-clay particles showed the best performance.

**Key Words:** Dense concrete, nano-clay particles, sulfate attack, chloride attack.

## MODELING OF COHESIVE CRACK VIA DISCRETE LEAST SQUARES MESHLESS METHOD

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**Abstract**
Numerical crack modeling is an important and basic problem for researchers. Also, Finite element has good

# Abstracts of Papers in English

## A DESIGN METHOD OF STEEL PILE-ABUTMENT CONNECTION OF INTEGRAL BRIDGES BASED ON FLEXURAL STRENGTH OF STEEL PILE

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**Abstract**

The construction of integral bridges solves difficulties due to the maintenance of expansion joints and bearings during serviceability; hence, it causes integral bridges to become more economic compared with conventional bridges. In the integral abutment bridge, the continuous deck slab and the abutments are integrated to form a rigid frame structure supported by single-row piles at the abutments, and normally single-row H-piles with bending about their weak axis are used as a system that resists against lateral loads. However, single-row H-piles with bending about their strong axis and various pile types (H-piles, circular concrete piles, steel-concrete composite piles, etc.) with single-row or multi-rows have also been used. The embedded length of pile inside the abutment of the bridges has a key role in providing shear and flexural resistance of pile-pile cap connections.

In this paper, first, a linear theoretical method was developed by authors to calculate the required embedded length of the pile, based on the plastic moment of steel pile. Then, the effect of spiral stirrup surrounding the steel pile was investigated in order to increase the strength of pile-pile cap connections. To evaluate the