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## Reliability finite element analysis of reinforced concrete beams without shear reinforcement

*Panagiotis Evangeliou, DIANA FEA BV*

In the modern structural engineering field, the significant influence of inherent uncertainties on system behavior constitutes the necessity of a stochastic approach to the engineering problems. However, the treatment of these uncertainties by the traditional deterministic engineering approach is questionable. The notion that this approach can be considered representative of all the possible scenarios of structural response, while based only on extreme and mean realizations of the specific parameters, is not true in most cases. Consequently, the deterministic approach cannot lead to rigorous assessment of the structural reliability. This possibility is, on the other hand, provided by stochastic approaches at the expense of increased solution system complexity and, consequently, increased computational effort.

The deterministic structural analysis field is, today, dominated by the finite element method implemented with finite element analysis software packages. In the case of reinforced concrete structures, a highly nonlinear response is exhibited due to extensive cracking, especially in the case of shear failure. The analytical models provided by the modern codes cannot realistically approximate this highly nonlinear response and, therefore, resort to a rather conservative approach. As a result, to examine the deterministic response of reinforced concrete structures, the implementation of nonlinear finite element analysis is necessitated.

Furthermore, the structural reliability assessment is currently carried out with semi-probabilistic approaches. However, the specific methods provide a conservative and limited approach to reliability assessment. On the other hand, high accuracy full-probabilistic approaches, such as Monte Carlo, are not applicable in combination with the computationally expensive finite element analysis due to the enormous computational cost required.

However, during the last decade, the probabilistic analysis has advanced with the development of adaptive response surface methods, which significantly reduce the computational effort while maintaining a high accuracy. Consequently, these methods provide the required framework for coupling of nonlinear finite element analysis with full-probabilistic analysis; leading, hence, to rigorous assessment of the structural reliability. The coupling of finite element analysis with adaptive response surface methods is implemented in DIANA FEA software under the probabilistic module named PROBAB. In this study, PROBAB is studied and applied for the structural reliability assessment of reinforced concrete beams with failure mode transition propagated by material and model uncertainties.

The examined reinforced concrete beams are part of an ongoing experimental project in TU Delft. The selected experimental data reflect the effect of the inherent material uncertainty to both the capacity and failure mode, flexural or shear, of the beam. Consequently, it is attempted to quantify this effect in terms of structural reliability by means of probabilistic nonlinear finite element analysis. To generate unbiased results, a robust finite element model is developed; a model that, for each realization of the stochastic material parameters, provides sufficient accuracy in the assessment of both the structural capacity and the failure mode. To this end, explicit studies of the material constitutive models, the loading conditions, the finite element mesh, and the numerical analysis scheme are undertaken. For this explicit study the selected experimental results and the existing analytical models are utilized. Eventually, the finite element model is calibrated and used as a "virtual experiment" for the probabilistic finite element analysis.

The probabilistic analysis is focused on the resistance side of the structure, affected by the material uncertainty. For deterministic action effects, the reliability index and design point are determined, and the probability of occurrence of each failure mode is computed. A parallel system of generated response surface functions is tested as a more automatized procedure for computing the probability of occurrence of each failure mode. A parametric study is carried out to realize the effect of the specified probabilistic analysis parameters. The sensitivity of the structural response to the assumed stochasticity of the material parameters is derived.

## How much additional reinforcement is required?

Subtitle: Case study to determine required reinforcement to withstand blast load in the Ketheltunnel

*Ricky Tai and Coen van der Vliet, Arcadis NL*

Many of the tunnels in the Netherlands are not designed to withstand a blast load due to an accident with a LPG truck. Partially this is due to the expectation of highly uneconomical designs of tunnels when considering this load. The Rijkswaterstaat, part of the Dutch ministry of infrastructure and environment, and owner of many tunnels in the Netherlands, wanted to gain more insight into the costs of including this blast load in the design of tunnels. Hence, Arcadis was asked in a case study to determine the additional reinforcement required when this load was considered in the current design of the existing Ketheltunnel.

Prior to the detailed analyses two simple calculations have been performed. In these calculations the tunnel section was schematised as a beam structure. For the first simple calculation the beams were converted into equivalent mass-spring system with a single degree of freedom. With this model the eigenfrequencies and maximum deflections have been approximated. The second simple calculation is based on the development of beam-structure-mechanisms via the formation of plastic hinges. This calculation is based on the energy balance and describes the relation between the deformation of the hinge, the plastic moment capacity of the beam, and the blast load. Valuable information about the effectiveness of adding reinforcement and other feasible design considerations have been gained through this simple calculation.

After the simple calculations, a 2-D model with plane stress elements has been modelled into the finite element software Diana FEA. An initial analysis with linear-elastic material properties provided a design with massive amounts of reinforcement that would not suffice to the detailing requirements. A sequential analysis with non-linear material properties and design considerations has been made to determine the required reinforcement.

## Steel–Concrete–Steel Sandwich Immersed Tunnels For Large Spans

*Kubilay Bekarlar, Marcel t'Hart, RHDHV*

Traditionele gewapend betonnen tunnels hebben een limiet voor de maximum overspanning in de dwarsrichting. Er was onvoldoende kennis of de staal-beton-staal sandwich afzinktunnels uitkomst kunnen bieden voor tunnels met een extreem grote overspanning in de dwarsrichting. Verder is er onderzocht hoe de interne krachten / spanningen zullen verdelen over een staal-beton-staal sandwich afzinktunnel voor een grote overspanning, ook wel de "structural response" genoemd. Voor de gedetailleerde analyse van de verdeling van interne krachten / spanningen is er gebruik gemaakt van een eindige elementen methode model (DIANA).

## *Modellering van beschadigd beton op basis van een uitbreiding van het uitgesmeerde scheurenconcept*

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De lezing betreft een lopend onderzoek naar het modelleren van beschadigd beton in het kader van de beoordeling van bestaande betonconstructies. Bestaande betonconstructies kunnen zijn beschadigd door opgetreden belastingen en aantastingsmechanismen (bijv. wapeningscorrosie). Voor een nauwkeurige beoordeling van de constructie dient opgetreden schade te worden beschouwd, omdat hierdoor het lokale materiaalgedrag wordt beïnvloedt en daarmee mogelijk ook het constructieve gedrag. Het modelleren van de specifieke processen die schade veroorzaken, kan moeilijk zijn, omdat (i) het complexe (fysische, elektrochemische) verschijnselen op microschaal kan betreffen, (ii) het veel rekenkracht kan vergen, en (iii) de vereiste gegevens vaak niet beschikbaar zijn. Bijgevolg blijkt de stap naar de analyse van het constructieve gedrag vaak te ambitieus.
Een alternatieve benadering is om beschadigd beton te beschouwen als "nieuw" materiaal met de aanwezigheid van schade als uitgangspunt. Hiervoor is het uitgesmeerde scheurenconcept in DIANA uitgebreid met de mogelijkheid om initiële schade mee te nemen. Teneinde rekening te kunnen houden met onzekerheden in de omvang en de ruimtelijke verdeling van de schade, kunnen de invoerparameters worden beschouwd als random fields. Deze modelmatige benadering van beschadigd beton is gevalideerd met behulp van een experiment op een onbeschadigde en een beschadigde betonnen ligger. Op basis van een beschouwing van het draagvermogen en het faalmechanisme zijn conclusies getrokken over de effectiviteit en de nauwkeurigheid van de modellering.

***20.30 uur Afsluitend drankje***