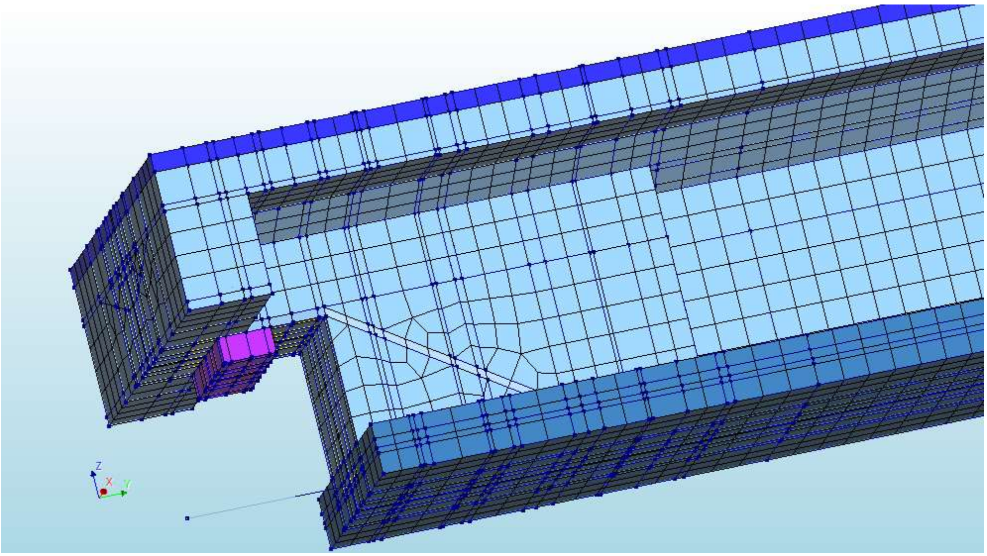
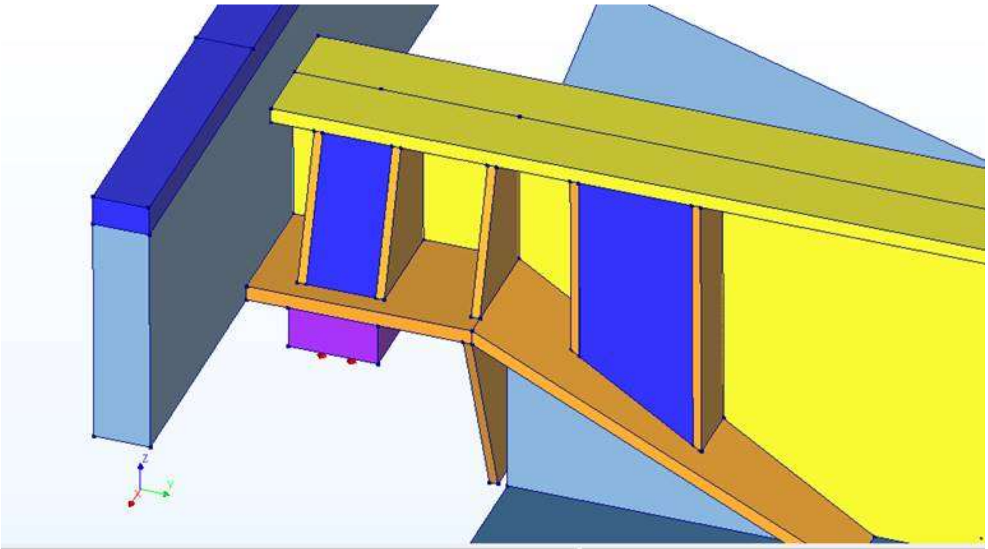
DIANA Users Association

Annual report 2017





Dr.ir. Ane de Boer
Chairman DIANA User's Association

Annual Report 2017

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1 Aim of the Association

The members of the Association are all users of the DIANA software package of DIANA FEA BV.
In this capacity, they have a considerable interest in gaining knowledge in the Finite Element Method and (numerical) mechanics, as well as in the further development and extension of DIANA.

To achieve this, the Association fulfils a coordinating role by taking stock of the members' needs in terms of research and development, and initiating new projects.

The Association is also a meeting place for the exchange of experiences with the software package.

Furthermore, DIANA FEA BV utilizes the Association to inform the Users on the DIANA package development progress.

2 Executive Committee 2017

During this reporting year, the Executive Committee consisted of:

Chairman:	Dr.ir. Ane de Boer, Centre for Infrastructures, Ministry of Infrastructures and the Environment, Utrecht (until April 1, 2017) Ane de Boer Consultancy, the Netherlands (From April 1, 2017
Secretary/ Treasurer:	ir. Coen v.d. Vliet, Arcadis Nederland BV, Amersfoort
Committee member:	ir. Henco G. Burggraaf, TNO Structural Reliability, Delft

The Executive Committee has mainly dealt with the following:

1. Discussion on continuing new research projects on the basis of a national and international user's wish list.
2. Organizing of the 11th International DIANA Users Meeting in Amersfoort, the Netherlands.
3. Continuing contributing to the set-up a database with publications related to DIANA or FEA.
4. Extending the existing e-mail database with foreign users in the fields of concrete, concrete mechanics, bridges and tunnels.
5. Preparation of general and technical meetings.
6. Association finance.
7. Progress in an international response/discussion forum around developments now and in the future related to Users Wishes.

3 Activities

3.1 General

The Association holds a general meeting of members twice a year, followed if possible by a technical meeting (lectures). In 2017 there have been held one general meeting and one technical meeting (lecture evening).

3.2 Technical lectures June 7th, 2017

Structural safety analysis of the 75 year old Maastunnel

Henco Burggraaf (TNO Structural Reliability)

The inspections in 2011 turned out that the concrete and reinforcement of the structural subfloor of the 75 years old tunnel was heavily damaged by chlorides as a consequence of the use of de-icing for years. The first question that arose was whether the structural safety was an immediate problem. The reinforcement bar diameter on parts is considerably reduced after all. Moreover, the bonding behaviour of the reinforcement is missing by spalling concrete parts. The structural floor should be able to bear approximately 25 m of water pressure. For the assessment of the structural safety in the current situation, 2D finite element calculations have been executed with DIANA in which the physical non-linear material behaviour of the concrete has been taken into account. The results of this numerical analysis will be discussed in details during this lecture.

Parametrical modelling with DIANA

Ritchie Vink (ABT)

The Python interpreter that has been added since the DIANA 10 release makes it possible to set up models parametrically. With repeatedly reappearing design of structures, the extra effort to set up models parametrically pays off. ABT calculates all wind turbine foundations parametrically and also uses the Python interpreter during post-processing. Moreover, an abstraction has been developed in which parametrical modelling can be faster than setting up a model in a more the traditional way.

Modelling a Preflex girder

Cees Jan van der Wilt (IV-Infra)

At some locations in the road infrastructure you can find a so-called Preflex girder structure, which was in the past the solution to overcome big spans. The 45 years old girders basically exist out of a prestressed steel profile share, imbedded in a concrete part.

Particularly the support part of this type of girder requires special attention due to the reduction of the steel part with all its strengthening webs between the flanges.

The presentation shows the modelling part of this type of girder, the construction stages which have an important influence on the stress distribution between steel and concrete and of course some results regarding structural safety will be discussed.

Foundation hydratation and cooling analysis railwaybridge Zuidhorn

Kris Riemens (ABT)

ABT has made heat-hydratation and cooling calculations in DIANA for the foundation blocks of a new railway bridge in Zuidhorn, the Netherlands.
The modelling of the cooling pipes, thermal boundary conditions, material properties and crack behaviour will be discussed.

3.3 International DIANA Users Meeting 1-2 November 2017, Arcadis Nederland BV, Amersfoort, the Netherlands

Wednesday, 1th November

Workshop ‘Seismic Analysis with DIANA’

The workshop on Wednesday 1 November aims at bringing together specific knowledge and expertise on the field of seismic analysis. The program is a combination of inspiring lectures and open discussions / work sessions.

Lectures:

Sander Meijers, Royal HaskoningDHV, The Netherlands
Seismic nonlinear time-history analyses for retrofitting in Groningen

Rick Bruins, ABT Wassenaar/BORG, The Netherlands
How Python scripting facilitates the postprocessing at the Boterdiep project

Miranda Kamphuis, Sweco, The Netherlands
Special NLTH-issues – how to…?

Tuba Tatar, Universidade do Porto, Portugal
Detailed numerical characterization of damage states of RC members

Gerd-Jan Schreppers, DIANA FEA BV, The Netherlands
Development wishes

Thursday, 2nd November

Lectures:

Theme: Assessment Requirement Approaches

Recent Developments of the NLFEA Guideline

Max A.N. Hendriks, Delft University of Technology, the Netherlands / NTNU, Norway
Ane de Boer, Ane de Boer Consultancy, the Netherlands
Beatrice Belletti, University of Parma, Italy

Summary
The Dutch Ministry of Infrastructure and the Environment is concerned with the safety of existing infrastructure and expected re-analysis of a large number of bridges and viaducts. Nonlinear finite element analysis can provide a tool to assess safety using realistic descriptions of the material behavior based on actual material properties. In this way, a realistic estimation of the existing safety can be obtained utilizing “hidden” capacities.

Nonlinear finite element analyses have intrinsic model and user factors that influence the results of the analysis. This document provides guidelines to reduce these factors and to improve the robustness of nonlinear finite element analyses. The guidelines are developed based on scientific research, general consensus among peers, and a long-term experience with nonlinear analysis of concrete structures by the contributors.

The new version of the guidelines 2017 can be used for the finite element analysis of basic concrete structural elements like beams, girders and slabs, reinforced or prestressed. The guidelines can also be applied to structures, like box-girder structures, culverts and bridge decks with prestressed girders in composite structures. The guidelines are restricted to be used for existing structures.

The guidelines have been developed with a two-fold purpose. First, to advice analysts on nonlinear finite element analysis of reinforced and prestressed concrete structures. Second, to explain the choices made and to educate analysts, because ultimately the analysts stays responsible for the analysis and the results. An informed user is better capable to make educated guesses; something that everybody performing nonlinear finite element analyses is well aware of.

The deliverables in this context are:
1 - Guidelines for Nonlinear Finite Element Analysis of Concrete Structures
2 - Validation of the Guidelines for Nonlinear Finite Element Analysis of Concrete Structures, Part: Overview of results
3 - Validation of the Guidelines for Nonlinear Finite Element Analysis of Concrete Structures, Part: Reinforced beams
4 - Validation of the Guidelines for Nonlinear Finite Element Analysis of Concrete Structures, Part: Prestressed beams
5 - Validation of the Guidelines for Nonlinear Finite Element Analysis of Concrete Structures, Part: Slabs

Multi-level assessment of a full-scale tested bridge deck slab

Jiangpeng Shu, NTNU, Norway

Summary
Reinforced concrete slabs without shear reinforcement are commonly used in many structural systems, such as bridge deck slabs. Punching/shear is usually the governing failure mode at ultimate of those RC slabs subjected to concentrated load. However, previous study has shown that existing models are too conservative. Thus, the aim of this study is to evaluate and improve the existing calculation model.
In this study, a "Multi-level Assessment Strategy" has been applied to a 55-year old existing reinforced concrete bridge deck slab with concentrated load near the girder. The punching/shear strength was calculated based building codes, Critical Shear Crack Theory and Nonlinear FE analyses. The difference between assessment methods at different levels has been discussed regarding punching and one-way shear behavior of slabs. In addition, a full-scale test was carried out to the bridge to calibrate the calculation model. Furthermore, the failure mode between one-way shear and punching was discussed. The influence of boundary condition, location of concentrated loading and arch action were investigated in the model. The shear force distribution was analyzed in different cases to evaluate the influences to the failure mode. The choice of effective to calculate the one-way shear resistance was discussed based on shear force distribution.
Results show that the failure mode to the slab was between punching and one-way shear. Shear force distribution is influence by cracking and the failure mode would be affected by factors such as boundary condition and location of concentrated loading.

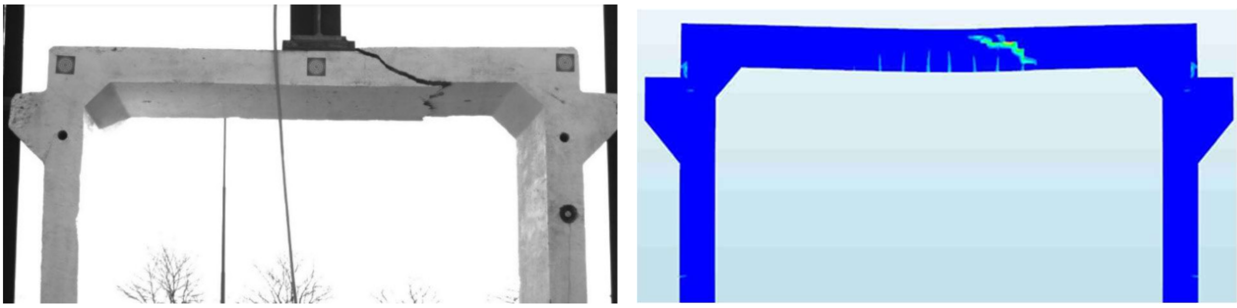
Theme: Assessment Applications

Numerical and experimental strength assessment of 45-year-old prefab culvert

Hikmet Uysal, Arcadis Nederland B.V., the Netherlands

Summary
The main question of this thesis is the result of a survey by 'provincie Zuid-Holland' (PZH), that has developed a 'uniform model' for the assessment of the structural safety of existing prefabricated culverts. PZH is considering the possibility of using generic parameters to decide on the strength of existing culverts in the area. The province wants to show that all culverts, given their size and other material characteristics, are strong enough to carry the traffic loads prevailing in The Netherlands. The PZH has decided to provide some elements of a replacement culvert (Schaapswegduiker) for the (destructive) determination of the strength. This has been realized based on the results of this thesis. The aim of the thesis is to determine the maximum load that can be carried and to access the structural safety of the Schaapswegduiker, in accordance with current regulations.
In order to answer this research question, a literature study was conducted to assess the structural safety of existing structures. Schaapswegduiker is assessed for traffic loads LM1 and LM2 in accordance with RBK1.1, NEN 8700, NEN 8701 and NEN-EN-1991-2.
First, a materials research has been performed to determine the proper output parameters for the calculations. Hereafter two calculation models have been prepared to validate the uniform model of PZH: a framework model (comparable to uniform model) and an advanced non-linear FEM model. The advanced non-linear calculation

has been carried out by means of a 2D DIANA-model. Using this model, I have made a prediction, a plan of action and a set-up for the test load that is carried out. The DIANA-model is calibrated with the results of the test. Lastly, the influence of the by ground enclosed culvert on the load-bearing capacity has been analyzed.
In short, the culvert meets the test for assessing the structural safety for both calculation models. An advanced model with a nonlinear calculation in EEM calculates a factor of 1.9 higher load-bearing capacity and UC, compared with a framework model which is linear-elastic. This factor includes the maximum negative influence of the culvert in the ground and a conservative calibration of the model (DIANA-model is calibrated up to a maximum of 81%). That means that this determined factor can actually be even higher.
PZH is recommended to go through the following phases when assessing other existing culverts in their area. Phase 1, design values should be used when there is enough information available about the culvert. When the UC does not meet, there should be continuation to phase 2. Here a materials research will be done. Precise determination of the material properties is important, especially the reinforcement configuration. It has been shown that it is worth paying extra attention to the reinforcement configuration. When the UC does not meet with the design values of the under limit of the design values of the measured values, there should be continuation to phase 3. Here, an advanced non-linear calculation with FEM is recommended, such as DIANA. The same material properties are assumed as in phase 2.



One of the most important results of the experimental (left) and numerical assessment (right).

Stability assessment of a masonry arch

Richard Roggeveld, Witteveen+Bos, the Netherlands
Frank Kaalberg, Witteveen+Bos, the Netherlands

Summary
In Arnhem (NL) rainfall in the northern part of the city is being transported by a main sewer called Moerriool. This sewer was built approximately 150 years ago, and consists of concrete slabs with a masonry arch. During inspection of the sewer, alarming damages were found. The masonry structure suffered severe subsidence, cracking, deformation and material deterioration.
A complete renovation was likely to be very costly, therefore remedial works needed prioritizing. No archives were available, all basic information needed to be gathered on site. In addition, various tests have been undertaken to find the propelling mechanisms, in order to be able to assess the stability of the structure and finally to list appropriate measures.

Geometrical and physical non-linear Diana-models were used to assess the stability of the arch under various circumstances, for instance due to variance in soil stiffness, wall thickness and material degradation.
The feasibility of 3 measures has been studied in more detail. Based on the results, the renovation plan was made and gave start to the works.

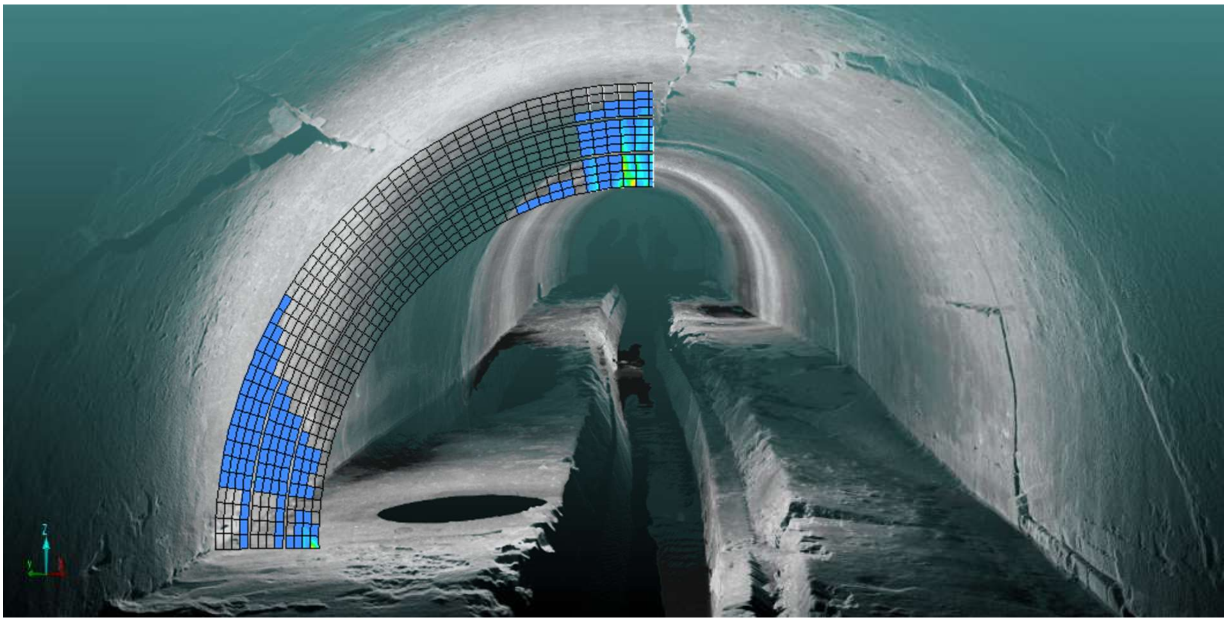


Figure 1: Diana-results, combined with a picture and laser scan

Theme: Additional Assessment Applications

Critical loading position for proof load testing of reinforced concrete slab bridges based on scripted FEM analysis

Yuguang Yang, Delft University of Technology, the Netherlands

Summary
As the bridge stock in the Netherlands and Europe is ageing, various methods to analyse the capacity of existing bridges are being studied. Proof load testing is one of the method to test the capacity of bridges by applying loads on the existing concrete bridges with small spans. Because of the fact that neither the actual traffic load nor the design traffic load required by Eurocode can be directly applied on the target bridge in real-life proof load testing, an equivalent wheel load has to be applied instead. The magnitude and the location of the equivalent wheel load is determined in such a way that it generates the same magnitude of inner forces in the cross section. Such calculation is usually done by linear finite element analyses (FEA). Whereas, different bridges have different geometry such as length, width, thickness, angles, number of spans and lanes etc. For each configuration, FEA has to be done first to determine the loading position. The main aim of this paper is to study the relation between bridge geometry and unfavorable loading positions (ULP). Based on that, a guidance tool is developed for the determination of the critical proof load testing locations for the practice.

To achieve this goal, a Python script has been developed using Diana FEA. The script enables the automatic generation and analysis of a bridge model with different geometries and loading conditions. By applying the Eurocode Load Model 1 at variable locations, the most unfavorable loading positions for the proof load are obtained at the corresponding boundary conditions. The output of the study provides a convenient tool for future proof load testing.

In search of additional load bearing capacity

Niels Kostense, Arcadis Nederland BV, the Netherlands
Coen van der Vliet, Arcadis Nederland BV, the Netherlands

Summary
Due to increasing traffic loads and modifications in concrete design rules existing bridges suffer from the potential risk not complying to the present building codes. In particular bridges with small spans are vulnerable to the increase of traffic load because of the higher ratio of live load compared to dead load. Arcadis is assigned to assess the structural safety of a relatively small pedestrian tunnel where refinements with respect to the analysis- and modeling approach are subsequently adopted.
In this project specific attention is given to the analysis approach to conduct a non-linear analysis with limited resources. This entails that the adopted strategy must be proportional to the size of the object, but reflects the real structural behavior with sufficient accuracy. The chosen analysis approach has to be proportional to the scale of the structure and requires an efficient strategy that determines the capacity to redistribute forces, but entails a limited modelling and computational effort.
The structure considered is a small pedestrian tunnel built up from prefabricated prestressed elements with a cast in place compression layer. The size of the structure does not automatically imply that the structural behavior is straightforward. For this particular object modeling and structural analysis should take into account the effects of prestressing, non-orthogonal reinforcement, orthotropy due to skewness and geometric discontinuities, different concrete properties of the composed slab and different construction phases. Accounting for all these properties in a physically nonlinear analysis resulted in a certain redistribution of forces where the required safety level has been verified. The effectiveness of the modeling techniques and practical use of the applied safety formats play a crucial part in this project and are evaluated.

Theme: Stability and Fiber Reinforced Concrete

Modelling of young hardening underwater concrete with steel fibers

Kris Riemens, ABT BV, the Netherlands

Summary
For basement structures, use is traditionally made of unreinforced underwater concrete as a temporary seal of the building site. Because the concrete is placed under water, the quality however remains uncertain and the material can behave brittle. Though meant to ensure a watertight building site, leakage problems often occur due to thermal shrinkage cracking. Use of traditional reinforcement in underwater concrete can be considered but is complex and expensive. Recent projects, such as Groninger Forum and Albert Cuypgarage, however have shown that the application of

steel fibers in the concrete mixture present a possible solution to this problem. Predicting the structural behaviour of the young hardening concrete mixture with steel fibers is a complex issue however, many different factors influence the structural behaviour and crack formation. Some of these factors include: thermal boundary conditions, mechanical boundary conditions, heat development of the concrete mixture, development in time and spatial variations of the mechanical properties and that of the post-cracking behaviour. Using the finite element program DIANA, a first attempt is made of modelling this complex phenomenon.

New options in DIANA Release 10.2

Gerd-Jan Schreppers, DIANA FEA BV, the Netherlands

4. Financial aspects 2017

Summury financial report

SAMENVATTING BIJ FINANCIEEL JAARVERSLAG 2017

Balans	31 december 2017		1 januari 2017	
ACTIVA				
Vaste activa	€ -			
		€ -		
Vlottende activa				
Vorderingen	€ 5 717		€ 797	
Liquide middelen	€ 26 298		€ 32 371	
		€ 32 014		€ 33 169
Totaal activa		**€ 32 014**		**€ 33 169**
PASSIVA				
Eigen vermogen	€ 31 905		€ 32 361	
		€ 31 905		€ 32 361
Kortlopende schulden	€ 110		€ 808	
		€ 110		€ 808
Reserveringen en voorzieningen	€ -			
		€ -		
Totaal passiva		**€ 32 014**		**€ 33 169**

Winst- en verliesrekening 2017	debet	credit
Netto omzet	€ -	€ 5 450
Kostprijs van de omzet	€ 1 935	€ -
Bruto omzetresultaat	**€ -**	**€ 3 515**
Personeelskosten	€ 3 729	€ -
Algemene beheerskosten	€ 496	€ -
Financiële baten	€ -	€ 255
Financiële lasten		
Resultaat uit gewone bedrijfsvoering	**€ 3 971**	**€ -**
Buitengewone baten en lasten	€ -	€ -
Resultaat (verlies)	**€ 456**	**€ -**

Penningmeester DOV:	Accordering kascommissie:	
datum: 15 februari 2018	datum: 10 juli 2018	datum: 10-07-2018
Coen van der Vliet	Johan de Boon	Kris Riemens

5. Publication list

ABT

Arcadis

Heijmans, R.W.M.G. and C. van der Vliet, Zinktunnel onder extreme omstandigheden, Cement, 2017/5, Aeneas, p. 52-58.

Uysal, H., Numerieke en experimentele bepaling van het draagvermogen van een bestaande prefab duiker uit 1971, Master Thesis, Delft University of Technology, Delft, 2017.

Chalmers University of Technology

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Shu, J.; Belletti, B.; Muttoni, A.; Scolary, M.; Plos, M. (2017). Internal force distribution in RC slabs subjected to punching shear. Structure and Engineering structures. Vol. 153 s. 766-781.

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Plos, M.; Shu, J.; Zandi Hanjari, K.; Lundgren, K. (2017). A multi-level structural assessment strategy for reinforced concrete bridge deck slabs. Structure and Infrastructure Engineering. 13 (2) s. 223-241.

Williams Portal N., Lundgren K. and Thrane Nyholm L. (2017): Flexural Behaviour of Textile Reinforced Concrete Composites: Experimental and Numerical Evaluation. Materials and Structures, 50:4. doi:10.1617/s11527-016-0882-9

CONFERENCE PAPERS:

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Delft University of Technology

V. Mariani, F. Messali, M.A.N. Hendriks, J.G. Rots, Numerical Modelling and seismic analysis of Dutch masonry structural components and buildings, 16WCEE, Jan. 2017.

A. Tsouvalis, J. de Oliveira Barbosa, E. Lourens (Delft University of Technology), Vailidation of a coupled FE-BE model of a masonry building with in-situ measurements, 16WCEE, January 2017

DIANA FEA BV

P. van der Aa (DIANA FEA BV), Automatic Reinforcement method using NLFEA, High Tech Concrete: Where Technology and Engineering Meet – fib 2017, Springer International Publishing

A. Tzenkov (Stucky); C. Frissen (DIANA FEA BV), O. Santurjian (Bulgarian Academy of Science), Icold Benchmark theme A: Cracking of a concrete arch dam subjected to harsh environmental conditions. Icold Benchmark – nb. presentation only, September 2017

S. Theodori (AF Gydro), G. Schreppers (DIANA FEA BV), Icold Benchmark theme B: Static and seismic analysis of a RCC arch-gravity dam and need for thermal stress considerations. Icold Benchmark – nb. presentation only, September 2017

J. Salamon (Bureau Reclamation), J. Manie (DIANA FEA BV), Icold Benchmark theme B: Static and seismic analysis of an arch gravity dam. Icold Benchmark – nb. presentation only, September 2017

L. Mejia (Geosyntec Consultants), C. Hoffmann (DIANA FEA BV), Icold Benchmark theme C: Stress and deformation analysis of Mornos dam with DIANA. Icold Benchmark – nb. presentation only, September 2017

M. Maren (IHE Delft), P. Evangeliou (DIANA FEA BV), Icold Benchmark theme D: Reliability assessment of gravity dam block by coupling a directional adaptive response surface full probabilistic method and 3D coupled flow-stress finite element analysis using the DIANA FEA software. Icold Benchmark – nb. presentation only, September 2017

Shen Ma, Ab van den Bos (DIANA FEA BV), Nonlinear analysis of reinforced concrete structures by Ecov method in SLS and ULS. High Tech Concrete: Where Technology and Engineering Meet – FIB 2017

D. Ferreira, W.P. Kikstra, G. Schreppers (DIANA FEA BV), M. Hendriks (TU-Delft); A. de Boer (RWS), Reduced nonlinear finite element models for quick-scan assessment of concrete infrastructure. Life-Cycle of Engineering Systems: Emphasis on Sustainable Civil Infrastructure

Ab van den Bos, Shen Ma (DIANA FEA BV), Michael Menting (ABT bv), Shear failure tests on large specimens RC/SFRC, including statistical repetition. High Tech Concrete: Where Technology and Engineering Meet – FIB 2017

Pim van der Aa, Jonna Manie (DIANA FEA BV), Simple to advanced finite element shape modelling with DIANA, High Tech Concrete: Where Technology and Engineering Meet – FIB 2017

A. van den Bos (DIANA FEA BV), Richard Groen (Twintec), Ultimate design – floors and screeds, Concrete Engineering International, January 2017

E. Goulas, G. Schreppers, M. Partovi (DIANA FEA BV), R.M. Gunn (Swiss Federal Office of Energy), Parametric layout of double-curvature arch dams using DIANA Finite Element Software, USSD, April 2017

Ministry of Infrastructure and the Environment & Delft University of Technology

Recommendations for proof load testing of reinforced concrete slab bridges Lantsoght, Eva; van der Veen, Cor; Hordijk, Dick; de Boer, Ane. 39th IABSE Symposium – Engineering the Future September 21-23 2017, Vancouver, Canada, REPORT, ISBN 978-3- 85748-153-6, pg 346-353

Proof load testing of the viaduct De Beek Lantsoght, Eva; Koekkoek, Rutger; Yang, Yuguang; van der Veen, Cor; de Boer, Ane; Hordijk, Dick 39th IABSE Symposium – Engineering the Future September 21-23 2017, Vancouver, Canada, REPORT, ISBN 978-3-85748-153-6, pg 2824-2831

Reliability index after proof load testing: Viaduct De Beek; E.O.L. Lantsoght, C. van der Veen & D.A. Hordijk, A. de Boer, ESREL, Safety and Reliability – Theory and Applications – epin & Briš (Eds)© 2017 Taylor & Francis Group, London, ISBN 978-1-138-62937-0

Extended Strip Model for Slabs Subjected to a Combination of Loads, Eva O.L. Lantsoght, Cor van der Veen, and Ane de Boer, fib SYMPosium 2017, Maastricht, the Netherlands, 12- 14 June 2017, High Tech Concrete, Where Technology and Engineering Meet

Determination of Loading Protocol and Stop Criteria for Proof Loading with Beam Tests, Eva O.L. Lantsoght, Yuguang Yang, Cor van der Veen, Ane de Boer, and Dick A. Hordijk, fib SYMPosium 2017, Maastricht, the Netherlands, 12-14 June 2017, High Tech Concrete, Where Technology and Engineering Meet

An Experimental Study on the Transition of Failure Between Flexural and Shear for RC Beams, Yuguang Yang, Cor van der Veen, Ane de Boer and Dick Hordijk, fib SYMPosium 2017, Maastricht, the Netherlands, 12-14 June 2017, High Tech Concrete, Where Technology and Engineering Meet

Royal HaskoningDHV

M.J.G. Hermens, H.G. Kraaijenbrink, S.J.H. Meijers, Advances in non-linear time history and modal response spectrum analyses for the seismic assessment of buildings in Groningen (Netherlands), Proc. of the FIB symposium High tech concrete: where technology and engineering meet, D.A. Hordijk and M. Luković (eds.), Springer Int. Publishing, June 2017, pp. 1505-1514

TNO Applied Geosciences, Utrecht, The Netherlands

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Osinga, S., Wassing, B.B.T., Pizzocolo, F., Fokker, P.A., Van Eijs, R.M.H.E., Van den Bogert, P.A.J. 2017. Geomechanical response to N_2 injection as a means of pressure maintenance in a sandstone reservoir. *Proceedings of the 51th US Rock Mechanics / Geomechanics Symposium (ARMA),* San Francisco, California, USA, 25-28 June 2017. Paper ARMA 17-326.

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TNO Structural Reliability

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University Minho

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