AUSTRALIAN NETWORK OF STRUCTURAL HEALTH MONITORING

Newsletter

Issue 27, March 2021
Contents

President Message

Tommy Chan

Professor in Civil Engineering, Queensland University of Technology

Dear All,

First of all, I would like to extend our warmest welcome to Khoa Nguyen of Data61 to the Advisory Board (AB) of ANSHM. In the last AB meeting on 7th Dec 2021, he was proposed to be invited to join the AB. I believe that he could strengthen the link between Data61 and ANSHM. I am so glad that Dr Nguyen is so keen to join the board and make contribution to the association.

Khoa, Welcome on Board!

Time seemed to be being accelerated because of COVID-19 and now we are in the third month of 2021. I pray that the pandemic could be controlled soon so that our lives could be returned to normal. However, I admit that we have also learnt a lot because of this virus, e.g. we have learnt that we need to adjust our mind to adapt to any sudden changes of our schedules and any sudden changes are not the end and we just need to be flexible and positive to face the change.

It is good to know that we have already started the COVID-19 vaccine rollout and hopefully Phase 1b of the plan targeting people over age of 70 and Aboriginal and Torres Islander people would begin from late March to early April, after frontline workers get jab in Phase 1a. Israel started their COVID-19 vaccine rollout on 19th Dec 2020, much earlier than us. Now (28th Feb 2021) showing 26th Feb 21 records, 7.96M people do have been injected and more than 3.29M have been fully vaccinated in Israel according to Our World in Data. Figure 1 shows Daily New Cases in Israel (Worldometers, 26th Feb 2021).

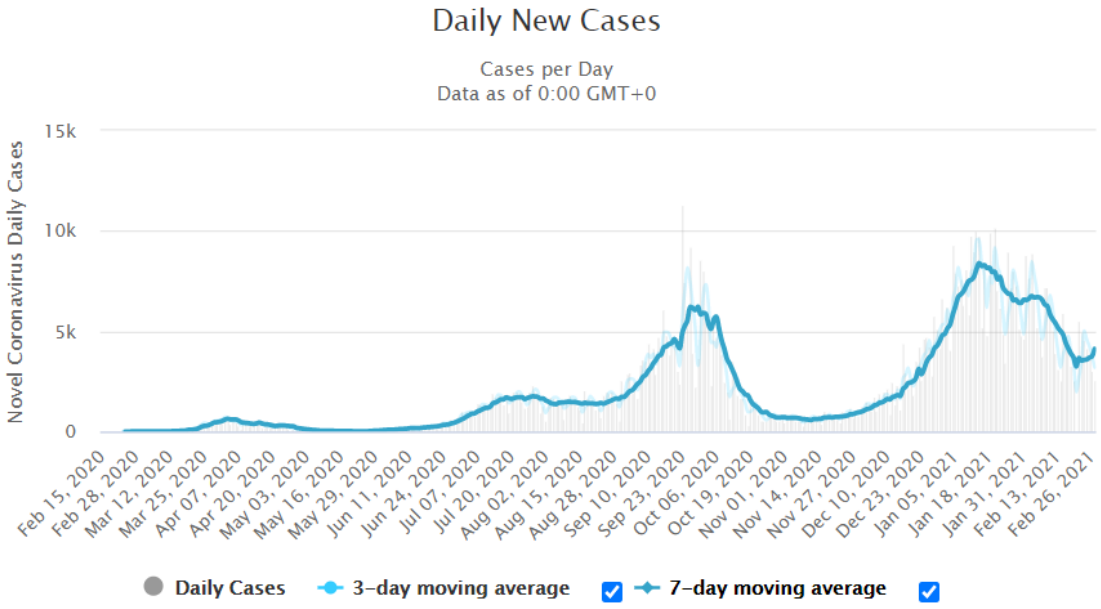

Figure 1: Daily New Cases in Israel (Worldometers, 26th Feb 2021)

It clearly shows a drop after the rollout. Actually, according to a study conducted by the country's largest healthcare provider Clalit, a 94% drop in symptomatic COVID-19 infections was reported among 600,000 people who received two doses of the Pfizer vaccine. It was also found that the same group was 92% less likely to develop severe illness from the virus (Reuters 16th Feb 2021). All these renew our hopes that travel, especially international travel may be possible in the late half of 2021. Hopefully our 13th ANSHM Workshop could be conducted in a real mode and we could meet each other face to face. Looking at the data, it seems that this could be possible. However even with the vaccines, we should not relax our COVID-19 precautions yet, especially those counties still having numerous new cases daily.

Many of you should have received my message dated 22nd February 2021 stating someone used my name as Tommy Chan with an email address (chairperson259@gmail.com) that I never knew to send

emails to a number of ANSHM Executive Committee members requesting for money. The swindler is very cunning by stating "Would be glad to receive your response through email ASAP, because I'm presently in a meeting now and am limited to calls…", trying to fool those who received the message will simply use "Reply" then they will be misled by sending the message to "me" without realising the email address is not my usual email address or call me directly. It will easily lead someone who is busy to fall into the trap. Technologies have helped us to do things much easier than before. We may have forgotten the phone numbers or email addresses of someone because of the "Reply" button which makes swindlers find it easier to trap people. After sending the alerting message, I received some responses that it seems that this kind of swindles is not uncommon. Someone received emails from someone pretending to be his or her Head of School and the other pretending to be the chair of an international association (very similar to this case). Below are the last two paragraphs of my message which I consider it will be good to re-state here for all of us to be alerted.

Some of the persons receiving the message, they simply ignored it (as they noticed that it was not my usual email address) and sent me a message alerting me. Another even contacted me directly to double check if I am the Tommy Chan sending him or her the message. These are all the right things to do to deal with this kind of spam mails.

I hope you have not lost anything due to this swindle. If so, please report it to the Police. If you have provided your credit card information to the swindler, please immediate cancel your card and also report it to the Police. If the card you used are your organisation corporate card, please inform your organisation about that as well.

Below are the updates of the month.

ANSHM Youtube Channel and the 12th ANSHM Workshop Recordings

I am pleased to inform you that I have uploaded the recordings of those who agreed to have their presentations to be uploaded to our Youtube Channel. Please see below I put down the links for those presentations. You can simply click the links or the corresponding presentations to watch the recordings. Those without links are the presentations that either the presenters do not agree to have their recordings uploaded or they have not responded yet. For those who have not responded, please email me or Lei Hou (lei.hou@rmit.edu.au) to indicate your consent to upload your presentations.

As mentioned in last updates, the link to the ANSHM Channel of "Australian Network of Structural Health Monitoring" is https://www.youtube.com/channel/UCUfUgHlWnVxj8-C3S5Nxjyw. Please subscribe and hit the "bell" icon so that you will get the notifications whenever we upload any new videos. Please also help us promote this Channel to share the link with those who are interested. For

those who have their presentations of the 12th ANSHM Workshop uploaded, may I ask the presenters to go to the ANSHM Channel on Youtube and check your presentations? Please let me know if you would like to add anything on the descriptions of your recordings and suggest the Tags for your videos. Please note that using appropriate Tags could help people locate your videos when they search for some information.

The 12th ANSHM Workshop Recordings (with Youtube Links)

Time	Monday, 7 December 2020	Tuesday, 8 December 2020
9:00-9:10am	Opening (https://www.youtube.com/watch?v=7IFan8Shg8g)	
9:10 - 10:30am	Session 1: Bridge Structural Health Monitoring (Session Chair: Prof Jianchun Li) 1. *"Structural Health Monitoring of Buildings and Bridges – Research at QUT: From Theory to Application and Implementation – Part I"* – Prof Tommy H.T. Chan & Prof David P. Thambiratnam & Dr Khac-Duy Nguyen, etc., Queensland University of Technology (QUT) (https://www.youtube.com/watch?v=1otsZs261jo) 2. *"Structural Health Monitoring of Buildings and Bridges – Research at QUT: From Theory to Application and Implementation – Part II"* – Prof Tommy H.T. Chan & Prof David P. Thambiratnam & Dr Khac-Duy Nguyen, etc., Queensland University of Technology (QUT) (https://www.youtube.com/watch?v=kBs5DAG1yeo) 3. *"Assessing the performance of alkali silica reaction (ASR) affected structures: modelling and*	Session 3: Non-destructive Techniques (Session Chair: Prof Tuan Ngo) 1. "Vision-based automated crack detection using convolutional neural networks for condition assessment of infrastructure" – Prof Tuan Ngo & Dr Tuan Nguyen University of Melbourne (https://www.youtube.com/watch?v=otQjcBvD9kE) 2. "The Use of Electron Migration Media as Moisture Sensor for Building Structure Health Monitoring" – Kenneth PAK C.W & Professor Jie Li, RMIT (https://www.youtube.com/watch?v=14ibUKjnGJo) 3. *"Creation of a digital twin for intelligent maintenance of port infrastructure"* – Dr Mojtaba Mahmoodian & Prof Sujeeva Setunge & Prof Kevin Zhang, RMIT; Dr Said Mazaheri, Beta International Associates (https://www.youtube.com/watch?v=zhdMuDY4YUk) 4. *"A Structural Health Monitoring System for the Sir Leo*

	monitoring" – Prof Jianchun Li, University of Technology Sydney (https://www.youtube.com/watch?v=aEok8G2zo2g) 4. *"Autonomous underwater robot for bridge pile cleaning and condition assessment"* – Dr Andrew To, Centre for Autonomous Systems, University of Technology Sydney (https://www.youtube.com/watch?v=GEkDuOHCsOE)		*Hielscher Bridge"* – Ben Itzstein & Nguyen Lu Dang Khoa & Filippo Ammazzalorso & Huy Pham & Raghav Chalapathy & Dilusha Weeraddana & Chen Cai, CSIRO; Dr Mehrisadat Makki Alamdari, UNSW
10:30 - 11:00am	Break		Break
11:00 - 12:20pm	Session 2: Data-driven Structural Health Monitoring (Session Chair: Prof Tommy Chan)	11:00 - 11:40am	Annual General Meeting (AGM)

	1. *"Image-based 3D Vibration Measurement for Structural Health Monitoring"* – Prof Hong Hao, Curtin Uni 2. *"AI-Assisted Structural Health Monitoring"* – A/Prof Jun Li & Prof Hong Hao & Ruhua Wang & Gao Fan & Ling Li & Senjian An & Wanquan Liu, Curtin Uni (https://www.youtube.com/watch?v=KjnevK0zfSg) 3. *"Visual-based structural health monitoring of bridge structures"* – Dr Ali Hadigheh & Prof Brian Uy & Prof Wije Ariyaratne, The University of Sydney 4. *"Investigation of effectiveness of crack detection using noncontact measurements and deep learning techniques*" – Dr Andy Nguyen & R.R. Chianese & Thiru Aravinthan & Allan Manalo, University of Southern Queensland; V.R. Gharehbaghi, Kharazmi University; Mohammad Noori, California Polytechnic State University	11:40 - 12:20pm	Session 4: Big Data Analytics for Structural Health Monitoring (Session Chair: Prof Hong Guan) 1. *"Finite Element Model Updating of a Cable-Stayed Bridge Using Structural Health Monitoring Data"* – Thomas Sharry & Hong Guan & Erwin Oh, Griffith University; Hoang Nam, Ho Chi Minh City University of Technology; Andy Nguyen, University of Southern Queensland (https://www.youtube.com/watch?v=z4sodPBEsf0) 2. *"Evaluation of Cross Laminated Timber Panels Non-destructively: Experimental and Numerical Study"* – Adam Faircloth, Salisbury Research Facility Qld; Loic Brancheriau, CIRAD France; Hassan Karampour & Stephen So, Griffith University; Henri Bailleres, Hyne Timbers & Son Qld; Chandan Kumar, Salisbury Research Facility Qld (https://www.youtube.com/watch?v=rKpqNAH19u4)
12:20 - 12:30pm	Group Photos	Break	
12:30 - 1:20pm	Break		

1:20-2:40pm	Industry Workshop: Structural Health Monitoring Practices (Facilitated by John Vazey) 1. Opening Speech (John Vazey, EngAnalysis) 2. *"Corrosion Monitoring on Concrete Structures - New and Old"* – William Ward, PCTE (https://www.youtube.com/watch?v=KxQNG0kznSs) 3. *"Iris CM™ from RDI Technologies Opens Up the World of Motion Amplification to Structural Health Monitoring"* –Andrew Gale, Optical Motion Technologies (https://www.youtube.com/watch?v=SfsKcY7_QMY)	
2:40-3:00pm	Break	Break

3:00-5:00pm	Advisory Board Meeting (ABM)	3:00 - 4:30pm	Industry Forum (Facilitated by A/Prof Colin Caprani & Govinda Pandey & John Vazey) Open Speech (https://www.youtube.com/watch?v=OTAEjMdAwGk) Special presentations before the forum discussion 1. *"What is the value of SHM?"* – A/Prof Colin Caprani & Dr Shaohua Zhang & M. Shihab Khan, Monash University (https://www.youtube.com/watch?v=4_t1IHi6xmI) 2. *"InfraTech: SHM and Beyond?"* – Govinda Pandey, Rockfield (https://www.youtube.com/watch?v=FgoCg96tGv8) 3. *"FiBridge: Digital asset management enabled by low-cost fiber-optic sensing and advanced analytics"* – Dr Ajay Raghavan, Xerox; Dusan Stojkovic, VicTrack (https://www.youtube.com/watch?v=4blcgTn971E)
		4:30-4:40pm	Closing (https://www.youtube.com/watch?v=G13pJBIom0I)

In our next Executive Committee meeting, we will discuss whether it is worthwhile to use this Youtube Channel to promote SHM technologies.

ANSHM Achievements and Activities 2020

In the last AGM, I gave a report on ANSHM achievements and activities. I hereby summarise them as follows:

1. *Membership*
   ANSHM has grown a lot since its establishment in 2009. We have now more than 100 members from 54 organizations that include 20+1 universities (1 from University of Surrey), 24 private companies, 6 government authorities and 3 research institutes. The number of the private company is increased by 4 since last year.
2. *Special Issues*
   In 2020, ANSHM published a special issue as volume 20 number 10 in the International Journal of Structural Stability and Dynamics, which was generated from 10th ANSHM workshop. This special issue is generated from the presentations at the 10th ANSHM Workshop as well as the ANSHM Special Session in ACMSM25, to celebrate our 10th Anniversary. We will continue to work on the publications for 11th and 12th ANSHM workshops.
3. *Newsletter*
   In 2020, ANSHM published four quarterly newsletters, Issue No. 23 to Issue No. 26. A lot of people from the industry find these newsletters helpful for them to understand SHM.
4. *Technical Workshop*
   We originally planned to have at least one technical workshop to be held in 2020. However, because of COVID-19, we need to postpone it to 2021 when the pandemic is under control.
5. *The 12th ANSHM Workshop*
   Because of COVID-19, the Workshop was held using a virtual mode. It opens another opportunity for ANSHM to start a Youtube Channel to upload recordings of the presentations at the Workshop. Many of the presentation recordings have already been uploaded to the Youtube Channel. The sponsorship of EngAnalysis to the Workshop is gratefully acknowledged.
6. *Website*
   Migration of the server for hosting ANSHM webpage to the Squiz Matrix platform has been successfully completed. Now besides, viewing by Desktop, ANSHM website can be well displayed via smart devices such phones and tablets.
7. *Research collaboration*
   As research collaboration is important, ANSHM will continue to promote SHM implementation via research collaboration through various Collaboration Platform, e.g. ITRH, Smart Crte CRC and Building 4.0 CRC.

8. *SHM Standards and Guidelines*
   Members of ANSHM EC Committee are sitting on the Australian Design and Standard Committees to prepare the commentaries for AS 5100 Part 7 and Part 5.

All in all, although COVID-19 has affected most of our normal lives, ANSHM still performed well in 2020. I should really thank all Executive Committee members for their supports and hard work during this difficult time.

The First Executive Committee Meeting in 2021

Our 1st Executive Committee Meeting in 2021 was held on 26th Feb 2021. Based on the tasks identified during the discussions in the last Advisory Board Meeting on 7th Dec 2021 and the last Annual General Meeting on 8th Dec 2021, we have allocated the EC members roles and duties as follows.

i. Hong Guan will continue to be in charge of ANSHM Webpage
ii. Lei Hou will continue to work on Webforum including the use of social media platforms like Youtube, Facebook, LinkedIn, etc.
iii. Jianchun Li as the Deputy President of ANSHM will prepare Who's Who of SHM in Australia, i.e. a document together with a standard ANSHM PPT for presentation for people to better understand what we have been doing and what we have achieved, plus a directory of our expertise in various areas of SHM.
iv. Alex Ng will continue to work as the Membership Officer and be in charge of the promotion of ANSHM normal and Core Membership.
v. Andy Nguyen will continue to be our Annual Workshop Coordinator as well as External Affair with the assistance of Jun and Alex. Andy will coordinate with Prof Jianchun Li and Prof Brian Uy to organize the 13th ANSHM Workshop in Sydney.
vi. John Vazey as a member of the Advisory Board will continue be our Internal Affairs and Industry Coordinator.
vii. Xinqun Zhu will continue to be in charge of ANSHM Technical Workshops/Short Courses with the assistance of Richard Yang.
viii. Xinqun and Mehri will be in charge of preparing SHM Technical Notes.
ix. Jun Li, Richard Yang, Mehri will continue to be working as ANSHM Newsletter Editors
x. Colin Caprani will be in charge of preparing SHM standard/guidelines.
xi. Tuan Ngo, Jianchun Li, Alex Ng, Colin Caprani and I will continue to be working in a task force for the Exploration of Funding Opportunities and research collaboration
xii. Hong Guan, Jianchun Li and I will continue to prepare the publication generated from the 11th ANSHM Workshop
xiii. Lei, Xinqun, Richard, Andy and I will explore the opportunities to prepare a special issue in a

high impact factor journal to publish papers generated from the 12th ANSHM Workshops.

Publication generated from the 12th ANSHM Workshop

As mentioned earlier, the publication will be published as a monograph by Nova Science Publishers Inc. The chapter coordinators are aiming to have their chapter ready for review by 30th July 2021, allowing two months for internal review and submit the ready-to-print version to the publisher by 30th Sept 2021.

ANSHM Mini-Symposium (MS26) in SHMII-10

As mentioned previously, the conference organiser has decided that SHMII-10 conference will be a fully online conference. We have received 8 papers submitted to ANSHM Mini-Symposium (MS26). Andy, Alex, and I have already completed the review of all the papers and the outcome of the review will be released by the Local Organising Committee of SHMII-10 soon.

The ANSHM Newsletter

I would like to remind you again that if you are interested in publishing an article in ANSHM newsletter, please register here https://docs.google.com/document/d/1XJX9qhxEfIkXSVluWDV5rvROuYySM-hWn-q9n8o-Tzw/edit. You are strongly encouraged to urge your PhD students to write articles reporting their research and find a slot to publish their works using the link. Besides, the editorial team will also take a more proactive role to invite members, especially those from the industry to write something about their successful stories on SHM or what they expect SHM could do for them and publish in the Newsletter. We will aim for having an active 2/3-year strategic publication plan at any time for our Newsletter.

In the next section, we will only have one article from our members. The article is from Western Sydney University and presents a study on structural behaviours of long span deep-corrugated reinforced steel box culverts.

With Kind Regards,

Tommy Chan
President, ANSHM
www.ANSHM.org.au

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Research profile | **Research publications** | **Google Scholar citations**

AUSTRALIAN NETWORK OF STRUCTURAL HEALTH MONITORING
Newsletter

A Study on Structural Behaviours of Long Span Deep-corrugated Reinforced Steel Box Culverts

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Abstract

Corrugated reinforced steel box culverts have been used extensively as economic alternatives to traditional medium- or short-span concrete girder bridges. In this research, the structural behaviours of buried long-span deep-corrugated reinforced steel box culverts is investigated by using finite element (FE)-based numerical modelling and simulations. Key parameters influencing the structural behaviours are identified and included, which include poor/well compacted soil, effectiveness of rib-stiffeners, connection, and interaction with surrounding soil. A parametric study is then conducted by using two/three-dimensional (2/3-D) FE models, which consider material nonlinearities of backfill soil, geometric nonlinearities in the steel arch and soil-steel interface. In addition, orthotropic material properties of the deep corrugated steel plates are considered in the proposed 3-D FE model. The FE results are validated with experimental results obtained from in-field testing and available in literature. It is found that the use of corrugated stiffeners as a kind of reinforcement for large span buried structures can significantly improve structural behaviours of a buried structure. It also suggests that material nonlinearities of backfill soil should be considered in FE modelling for accuracy and a suitable material nonlinear model should be also selected. In addition, the relative slippage of the corrugated steel plates caused by slotted bolt-hole connections influences the accuracy of numerical results.

Keywords

Structural behaviour, long-span deep-corrugated reinforced steel box culvert, finite element modelling, material nonlinearities, and in-field measurement.

Introduction

Corrugated reinforced steel box culverts generally have an elliptical arch cross section and soil cover that is small relative to the span. The stability of these buried steel culverts is critical which are significantly influenced by backfill soil, elastic modulus of soil, construction organisation, and compaction during the backfill procedure. Figure 1 shows a collapsed roof of a long span steel culvert structure during its construction. This collapse occurred when the contractor, working without supervision over a weekend, graded the fill over the top of the culvert so that it sloped from one side to the other. The culvert was unable to sustain the unsymmetrical load imposed by the sloping fill, and thus it collapsed.

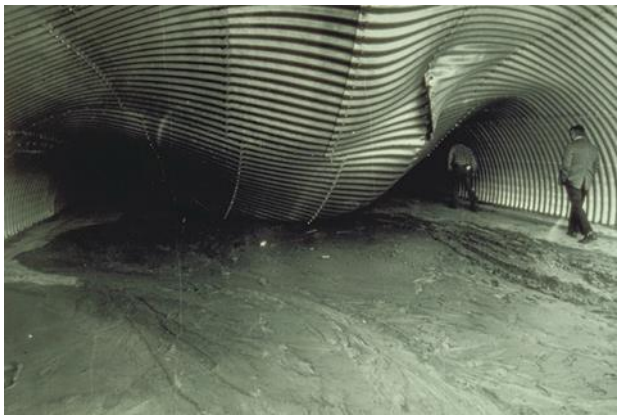


Figure 1: Roof collapse of a steel culvert structure, USA, 1979.

The structural performance of long span tunnels can be improved by using stronger materials or by incorporating rib stiffeners. One example is long-span deep-corrugated reinforced steel box culverts (also known as Super-Cor®), developed by Ingal Civil Products and some other companies. However current code recommendations and design practices do not provide any procedures or guidelines to assist with the design of the deep-corrugated reinforced steel box culverts. Therefore, it is critical to evaluate effects of the continuous reinforcement, deep-corrugated reinforced steel plates and the fastening system of the structures (bolts, shear studs and holes). However due to the complexity of such structures, their structural behaviours are not fully understood due to their diverse designs and uncertainties from working environment.

In this study, aiming to provide a better understanding on such structures, buried long-span deep-corrugated reinforced steel box culverts are modelled by using two/three-dimensional (2/3-D) FE models with considerations of material nonlinearities of backfill soil, geometric nonlinearities in the steel arch and soil-steel interface, and orthotropic material properties of the deep corrugated steel plates (only for 3D models). Via conducting the paramedic study, the structural behaviours of the

culverts are determined and influences of the key parameters are determined, which are useful for the design and construction for such structures. The validation of the numerical models is conducted by comparing the results with experimental results obtained from in-field testing and available in literature.

2/3-D FE Modelling of Long-span Deep-corrugated Reinforced Steel Box Culverts

In this study, two typical soil-buried shell culverts manufactured by Ingal Civil Products were considered as shown in Figure 2 (a): Culvert 2H with a 10.5-m large span crown and haunch rib-stiffened and Culvert 2G with a 5.9-m medium span, crown rib-stiffened, respectively. These culverts were buried and tested as shown in Fig. 2(b). In the testing, these culverts were subjected to both dead and live loads.

(a) (b)

Figure 2: Mandalee Super-Cor rib reinforced corrugated steel box culverts, Queensland, Australia, 2002 (Ingal Civil Products): a) Steel box culverts; and (b) Live load testing on buried culverts

Two finite element models were devised in this research for conducting nonlinear finite element analyses: a) 2-D model and b) 3-D model and used to study structural behaviours of these culverts under the loads applied during the soil backfill operation and the loads imposed by a test truck load driven over the culvert. The 2D models are for long-span culverts, such as the Culvert 2H and 3D models are appropriate for short-span culverts, e.g., the Culvert 2G.

The modelling and simulations of the culverts were developed by using the well-known commercial finite element package – ANSYS and those important performance characteristics of the culverts

including deformation, strain, stress and bending moment can be extracted. These models are consisted of steel box culverts and surrounding soils and thus the interactions between the structures and soils can be determined too. The culverts were assembled by using corrugated steel plates and its material model is steel. Considering potential large deflection, its geometric nonlinearities were considered in current models. Moreover, the corrugated steel plates give the arch greater strength in the longitudinal direction than in the transverse direction, therefore, it is orthotropic in nature and it exhibits different stiffness in two different orthogonal directions. As a result, corrugated steel plates and steel ribs can be modelled as an equivalent orthotropic plate.

The soil is regarded as nonlinear, inelastic, and highly dependent on the magnitudes of the stresses in the soil. The stress-strain diagram of Duncan and Chang's nonlinear elastic (Hyperbolic) model (Zhang, 2004) was used and implemented in ANSYS as shown in Fig. 3

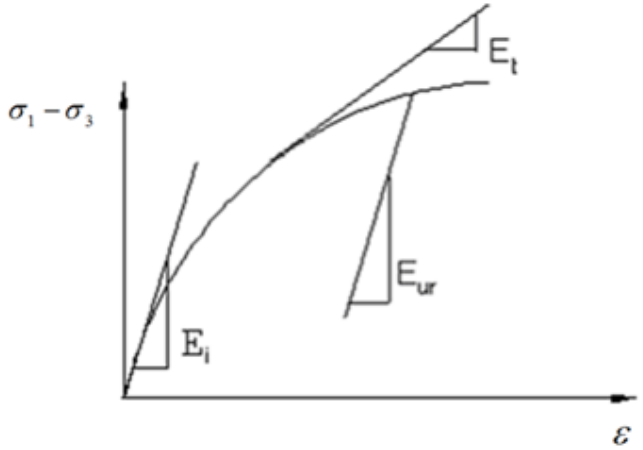


Figure 3: Duncan and Chang's nonlinear elastic (hyperbolic) soil model

Relative movement occurs between the soil and the steel walls of the culvert during the construction procedure and under live load. Moreover, the friction between soil and steel may influence the structural behaviours of the culvert too.

In the 2D model for the Culvert 2H, both culvert structures and soil were discretised by using 2D 8-node plane-strain finite elements. The model has the advantage of reducing the computing requirements considerably by eliminating one dimension from consideration. The interface between steel culvert and backfill soil was modelled using surface-to-surface contact elements with a friction coefficient of 0.36. These contact elements allow compression between the two surfaces to be transferred but do not transfer any tension. Two-dimensional models were developed to capture

structural behaviour of the Culvert 2H at a section approximately through the centreline of the road and the finite element mesh for the Culvert 2H is shown in Fig. 4.

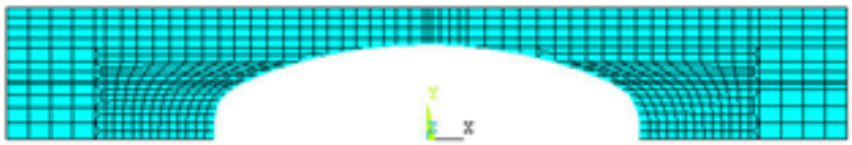


Figure 4: The finite element mesh of the model for the Culvert 2H

For the 3D model of the Culvert 2G, four types of finite elements were used to create the 3-D model for the Culvert 2G. These were the SHELL63 elastic shell element to simulate the corrugated steel plate described earlier, the SOLID95 3-D 20-Node structural solid element for the backfill soil, the 3D TARGE170 element and the 3D CONTA174 element to simulate the interaction surface between the steel plate and backfill soil. The friction between soil and steel was simulated using a friction factor of 0.36 for the contact elements. The mesh of the 3D finite element model of the Culvert 2G is shown in Fig. 5.

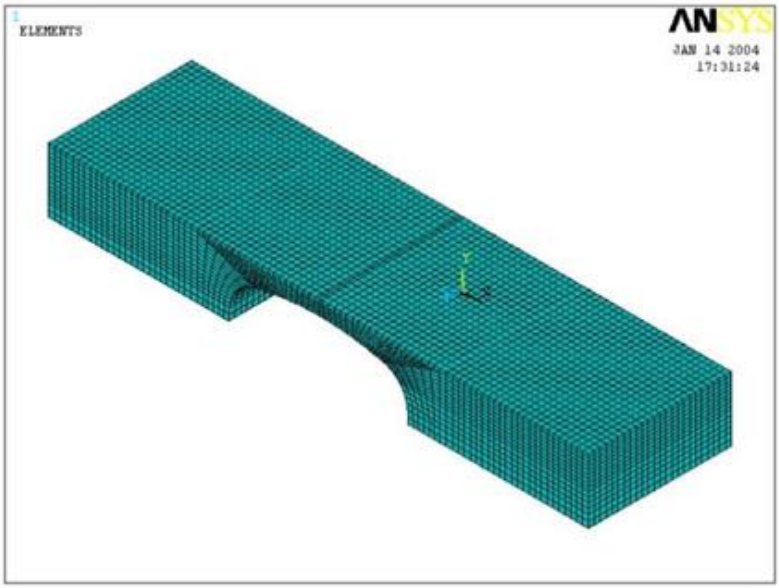


Figure 5: 3D finite element mesh of culvert 2G

The loads applied in the culverts are a) dead load from back fill soil and b) the live load for a 45.2-t truck adopted based on the static truck field test as shown in Fig. 1(b).

To validate the 2D FE models used later for parametric studies and to establish the accuracy of FE results, a comparison with in-field testing undertaken by Ingal was made.

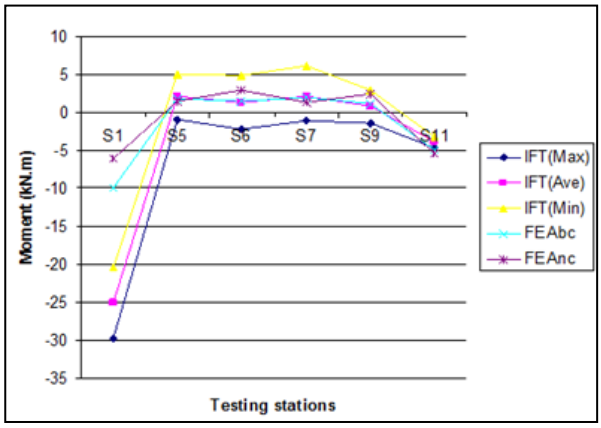


Figure 6: Moment of the Culvert 2H with dead load only

The results of analysis of the two 2D FE models, FEAbc and FEAnc, for the self-weight of soil were in reasonable agreement with the averaged results of the in-field testing. The results of the FEAbc model (with bolt connections) were better than the results of FEAnc (without bolt connections), particularly near the ends of the culvert (Stations S1-S3 and S9-S11). The results of axial force and bending moment of the two FEA models at each station were close to the average value of the in-field testing. They also fell between the maximum and minimum results of the in-field testing. Hence, the 2D FEA results of the self-weight of soil from ANSYS nonlinear analysis are acceptable. Similar results can be found in Fig. 7 for 3D FE model's validation.

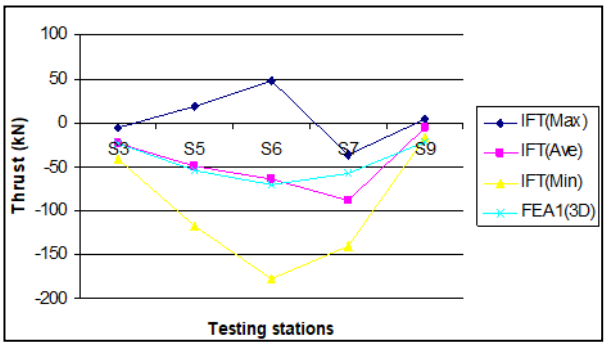


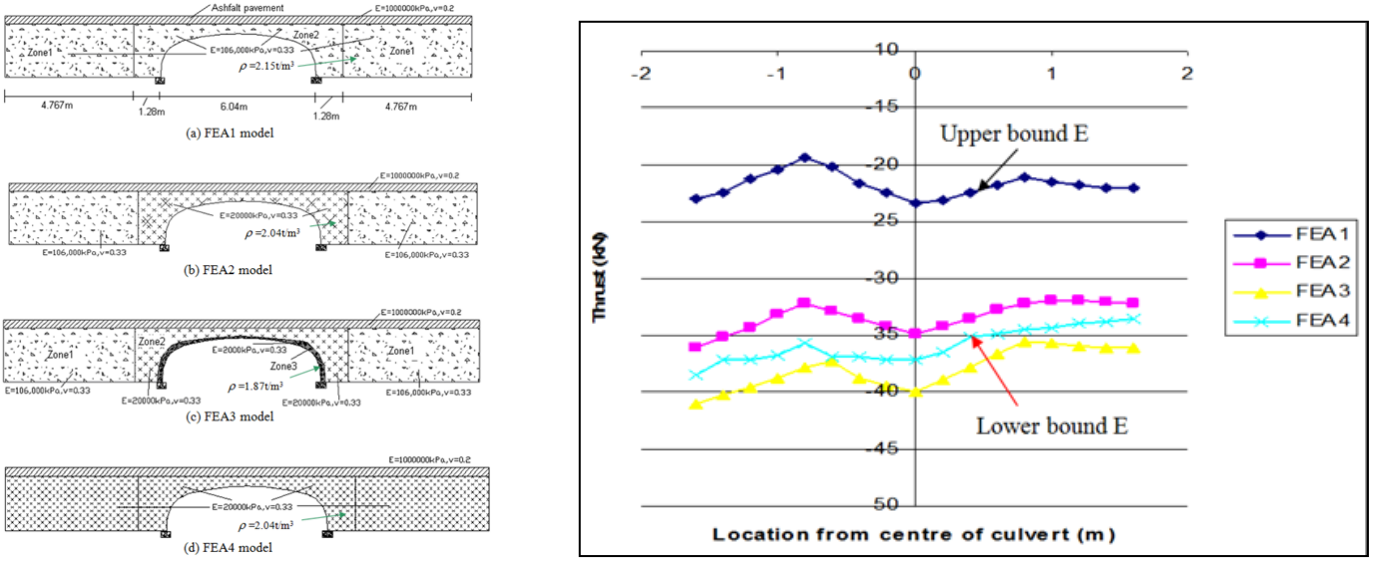
Figure 7: Thrust of the Culvert 2G (dead load only)

Results and Discussion

Various studies were undertaken to examine the performance of buried culverts, and to investigate the capability of numerical models to predict the in-field responses.

Effects of Soil Elastic Modulus and Density

The material characteristics of soil are nonlinear, inelastic and highly dependent on the magnitudes of the stresses in the soil. The two main properties of backfill soil that can influence the behaviour of a culvert are the elastic modulus, E, and the soil density, ρ. Both these values are dependant on the quality of soil compaction. The E value of backfill soil has a wider range, between 200,000 to 20,000 kPa for sand and gravel material. The density is less variable, ranging from 1.867 t/m3 (for very loose soil) to 2.152 t/m3 (for well compacted soil). Four FEA models were considered with different E values of backfill soil to perform the parametric study (dead load only) as depicted in Fig. 8 (a).



(a) (b)

Figure 8: (a) Four FEA models with different initial elastic modulus value E; (b) Hoop thrust of the Culvert 2G (dead load only)

According to hoop thrusts shown in Fig. 8 (b), the maximum value from the upper bound E was 37% less than the lower bound, and the minimum value from the upper bound E was 39% less than the

lower bound. It is apparent that good compaction of the backfill soil (upper bound E value and higher density ρ) caused a significantly lower circumferential axial force than the lower bound E value. In addition, the hoop thrust forces from the FEA3 model were the highest, and it was 6.8% higher than the lower bound. It is apparent that the lower E value and density of the backfill soil in the thin ring zone around the culvert has a slight effect on the overall axial force distribution on the culvert.

The bending moment distributions predicted by the FEA models are shown in Fig. 9. For both the lower bound and upper bound cases, the maximum positive bending moments were located at the crown and the maximum negative values were located at the sides. However, the maximum positive value from the upper bound E was approximately two times higher than the lower bound, whereas, the maximum negative value from the upper bound E was approximately 30% lower than the lower bound value. It is apparent that good compaction of the backfill soil (upper bound E value) caused a higher positive bending moment at the crown.

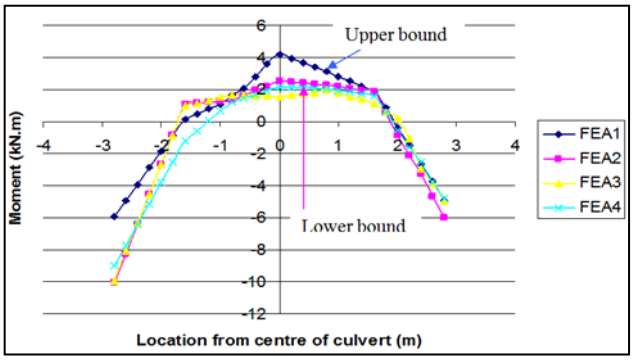


Figure 9: Bending moment of the Culvert 2G (dead load only)

Effects of Live Load Distribution

To consider the loading distribution from the truck on the culvert, the FEA results from different locations were assessed. One set of results were taken directly below the wheels (FEAw). The other set of results were taken on the culvert directly below the centreline of the road (FEAcl). Results were determined at 200 mm spacings. Fig. 10 show the culvert configurations and loading locations.

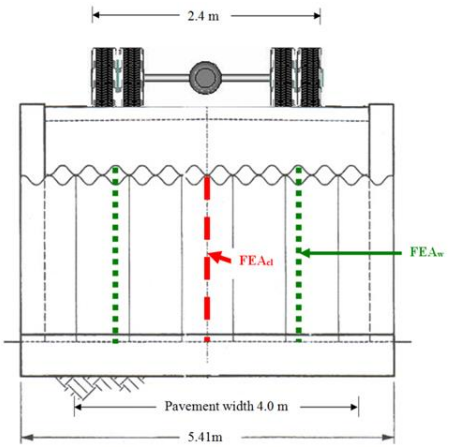
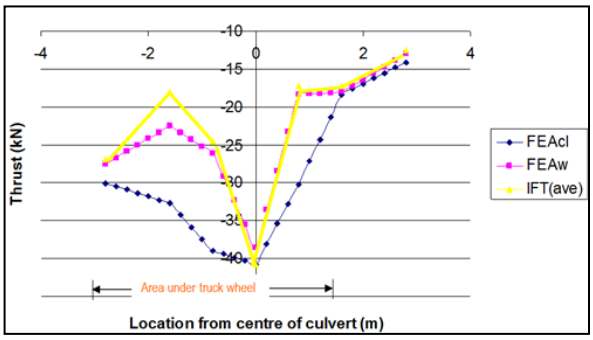
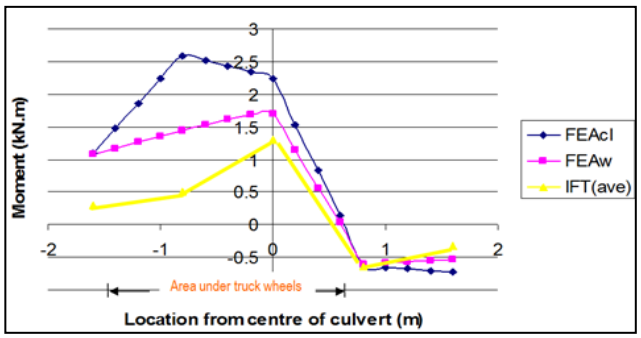


Figure 10: Live (truck) load projection onto culvert

These models were utilised to investigate the out-of-plane truck load distribution with respect to its thrust and bending moment. According to Fig. 11, the FEAw results more closely match the average in-field test results (IFTave). This is expected because the in-field test results were recorded in the region directly below the truck wheels (as simulated by FEAw). The results of FEAcl, however, reveal that the maximum stresses are higher below the centreline of the road than below the wheels (Fig. 48). In the area not under the truck wheels the results for in-field testing, FEAcl and FEAw are closely matched, because there is no truck load effects.



(a)



(b)

Figure 11: (a) Hoop thrust and (b) Bending moment of the Culvert 2G under live (truck) load

Conclusions

The structural behaviours of long span deep corrugated reinforced steel box culverts with rib stiffeners, under the influence of backfill soil and truck loads, have been investigated by using nonlinear finite element analyses with the commercial finite element package, ANSYS. The nonlinearities considered in this study included material nonlinearities, geometric nonlinearities, and contact nonlinearities at the soil-steel interface. Two case studies via using 2D and 3D FE models were conducted for a medium span culvert and a long span culvert, respectively, and their structural behaviours were determined. The numerical results obtained in FEA were found good agreement with those data obtained from in-field measurements supplied by Ingal Civil Products.

The validated FEA models were then used to undertake a parametric study. The effects of soil elastic modulus and soil density, and truck loading location were considered. Key findings are presented below:

- The effects of soil elastic modulus and density was assessed by comparing the results from four FEA models with different elastic modulus E and density ρ. It was found that in all cases the maximum hoop thrust forces were located at the crown and the minimum values were located at the haunch. It was found that good compaction of the backfill soil (higher E, higher soil density ρ) caused a significantly lower circumferential axial force.

- For both lower bound E and upper bound E cases, the maximum positive bending moments values were located at the crown and the maximum negative values were located at the sides. It was found that good compaction of the backfill soil caused a significantly higher positive bending moment at the crown and a moderately reduced maximum negative bending moment at the sides. This result was unexpected and will require further investigation in the future.

- The effects of the location of the projected truck load on the culvert was considered by comparing results from FEA models simulating load directly under the truck wheels and load directly under the centre line of the road. It was found that when the truck load was applied on the culvert structure, the maximum displacement, hoop thrust and bending moment occurred at the centre line between the truck wheels. It was observed that as the culvert length changes the bending moment and axial stresses change also. These stresses will be dependant on the location of the truck wheels and the distribution factor employed to project the loads onto the culvert structure, as well as the boundary conditions of the structure.

References

R. Zhang. The behavior of long span deep-corrugated reinforced steel box culverts. Thesis of Master of Engineering. Faculty of engineering. University of Technology, Sydney. September 2004. P26-34. Sydney. Australia. 2004.

A. Campbell. Three-dimensional finite element modelling of corroded corrugated metal pipe culverts. Thesis of master's degree of Engineering. Dalhousie University, Halifax, Nova Scotia. April 2018.

T. Elshimi. Three-dimensional nonlinear analysis of deep-corrugation steel culverts. PhD Thesis. Department of civil engineer. Queen's University. Kingston, Ontario, Canada. April 2011.

G. Abdel-Sayed, B. Bakht and L. Jaeger (1993). Soil-steel bridges. McGraw-Hill, Inc. New York.

G. Abdel-Sayed and S Salib. "Minimum depth of soil cover above soil-steel bridges". Journal of geotechnical and geoenvironmental engineering. August 2002.

Australian Standard. Long-span corrugated steel structures. Part 1: Materials and manufacture. AS3703.1-1989.

Australian Standard. Long-span corrugated steel structures. Part 2: Design and installation. AS 3703.2-1989.

Australian/New Zealand Standard. Buried corrugated metal structures. AS/NZS 2041:1998.

J. Duncan. Long-span metal culverts. University of California. College of engineering. USA. 2002.

K. El-Sawy. "Three-dimensional modeling of soil-steel culverts under the effect of truckloads". Thin-walled structures. 41 (2003) 747-768. January, 2003.

T. McGrath, I. Moore, E. Selig, M. Webb and B. Taleb. Design examples for large-span culverts. Supporting material for NCHRP report 473. National research council. 2002.

P. Byrne, T. Srithar and C. Kern (1990). Field measurements and analysis of a large diameter flexible culvert. Structural performance of flexible pipes. A.A.Balkema Publishers. Rotterdam. P27-38.

T. McCavour, T. Morrison and M. Winters (2000). Long span reinforced deep corrugated structural plate arch. Transportation research board 79th annual meeting. January 9-13, 2000. Washington, DC.

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