PART 2: PROGRAMME PROJECT INFORMATION

2.1. Project No. 3

Title	***Risk consideration for safe, effective and sustainable structures***		
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2.2. Tasks and deliverables

(List all tasks and deliverables that were planned for reporting period, list responsible partner organizations, give status, e.g. delivered/not delivered)

Target: *Develop new methods of risk assessment for buildings and structures to ensure their safe, efficient and sustainable operation.*

The Project is divided in three parts where each part have its own core task:

Core task 1: *Investigation of the dynamic characteristics of Latvian road bridges and determination of their impact on construction reliability, to develop the new methods for assessment of structural risk, reliability and robustnes;*

Core task 2: *Development of the methodology for experimental acquisition of dynamic characteristics (modal frequencies, mode shapes, modal damping) of structural elements with the presence of damage (different failure modes) for structural health monitoring;*

Core task 3: *To develop innovative smart structure with using of removable natural resources with the increased durability and reliability for structural and infrastructural purposes.*

Time frame for the core tasks is given in Annexes 3-A, 3-B and 3-C.

In addition, specific tasks related to completing core tasks of each Project parts are defined in every Period of the Project corresponding to the calendar year.

No.	Tasks	Deliverable	Responsible partner	Status
1.1.	Modeling of bridge and vehicle interaction, taking into account the type of the vehicle, type of the span structure, and pavement eveness	Method for investigation of vehicle and bridge interaction	A.Paeglitis, Department of Roads and bridges, Institute of Transport infrastructure engineering, RTU	In progress

1.2	Approbation of theoretical probability distribution models of bridge loads in Latvia. Analysis of traffic load data	Method of traffic data analysis	A.Paeglitis, Department of Roads and bridges, Institute of Transport infrastructure engineering, RTU	In progress
2.1	To develop method for localization of damage site and evaluation of damage size in various structural elements by using appropriate signal processing techniques experimentally measured dynamic parameter changes.	Methodology of damage identification in different type of structural elements (beam, plate, sandwich)	S. Rucevskis, Department of Composite Materials, Institute of Materials and Structures, RTU	In progress
2.2	To develop new technologies for monitoring and diagnostics of aviation engines and various elements of rotary machines.	Recommendation on monitoring and diagnostics of dynamic systems.	S. Rucevskis, Department of Composite Materials, Institute of Materials and Structures, RTU	In progress
2.3	To develop method for pre-stress loss estimation in pre-stressed steel reinforced concrete structural elements.	Method for pre-stress loss estimation in pre-stressed steel reinforced concrete structural elements.	S. Rucevskis, Department of Composite Materials, Institute of Materials and Structures, RTU	In beginning
3.1	Data generalization for development of design procedure for load-bearing elements from cross-laminated timber.	The data were generalized for development of design procedure for load-bearing elements from cross-laminated timber during the Period 1. The considered procedures are based on the LVS EN 1995-1-1, effective strength and stifness method and transformed section method.	D.Serdjuks Department of Building Constructions Institute of Structural Engineering and Reconstruction	In progress

Tasks for Period 1	Main results
1.1. Modeling of bridge and vehicle interaction, taking into account the type of the vehicle, type of the span structure, and pavement eveness	Method for investigation of vehicle and bridge interaction
1.2. Development of method for	Method for prediction of traffic load

prediction of live load action combinations	combinations

In the first period was caried out the analysis of the dynamic characteristics of the bridges obtained from the bridge load tests with dynamic loads during the last 20 years. The traffic load cause not only a static, but also a dynamic action on the bridge that affect the structural performance. These effects can be indicated by different dynamic parameters like – natural frequency, bridge logarithmical decrement, bridge acceleration and dynamic amplification factor (DAF). Dynamic amplification factor is the most widely used parameter, because it shows amplification of the static effects on the bridge structure. Results show that for bridges road surface condition is a very important factor. If road surface has ice in the winter or potholes then heavy traffic driving with low speed can decrease load carrying capacity of a bridge. In the Eurocode 1 (EN 1991-2:2003 Actions on structures. Traffic loads on bridges) a generalized DAF value should be applied to the worst static load case.

Obtained results show that DAF values for reinforced concrete and pre-stressed concrete bridges does not depend only on span length but there are many other factors that influence DAF. Results show that for bridges road surface condition is a very important factor. If road surface has ice in the winter or potholes then heavy traffic driving with low speed can cause a lot of damage.

Bridge natural frequency did not correlate with the bridge span length for pre-stressed concrete bridges, however for simple concrete bridges there was a tendency for natural frequency to decrease when span length increased. However there were correlation between natural frequency and DAF - for higher natural frequency values DAF values were smaller.

Overall DAF values for even pavement were within range 1,0 to 1,4 and are in the range proposed in the Eurocode 1. Hence proposed values are reasonable for good pavement condition.

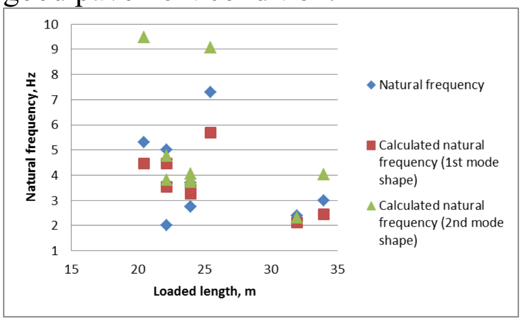

Fig.1 Natural frequency dependence on loaded length

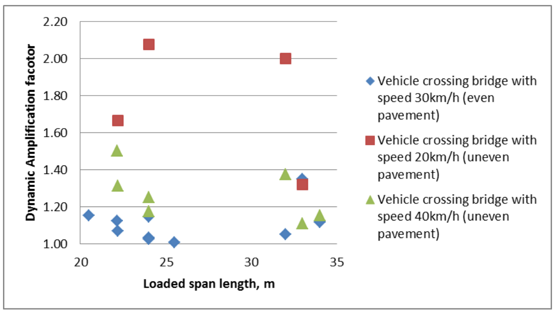

Fig.2 DAF dependence on loaded length

Because of the DAF value correlation with evenness of the bridge pavement, there should be regular bridge maintenance to assure good pavement conditions of all time hence significantly large DAF values can decrease load carrying capacity of the bridge.

Traffic weight data used in this study were collected from two WIM systems installed on highway A1 and A3 in Latvia where truck traffic is one of the highest in country. Vehicles were measured with piezo-electric sensors installed in the surface of the pavement.

In this study comprehensive WIM data cleaning was performed based on four different types of filters. Then cleaned data were used to calculate uniformly distributed loads for 200, 300, 400, 500, 600 meters long bridges spans were calculated.

Load values decrease with an increase in bridge span and a decrease in amount of trucks in traffic flow, although there are some exceptions. They could have arisen because cars that were included in the traffic flow was selected randomly but chronological order was preserved, it is therefore possible that cars have been included in the middle of a long truck platoon, that has been preserved in other scenarios.

If compared to UDL of the most loaded lane in LM1. even the loads calculated from first traffic scenario where traffic flow consists of only trucks in traffic flow are lower than 27 kN/m, the only exception here is A3 Lane1 200 meter span, but that has been addressed in conclusion 2. But it has to be noted that calculated loads have not been increased to provide room for future increase in truck weights.

If load calculated from 7th traffic scenario that simulates traffic flow with only cars in it is compared to the load model's 1 remaining lane loads (7.5 kN/m), it can be seen that calculated load is much lower than the ones currently used, however it would be unreasonable to assume that there would be a lane without any trucks.

These calculated loads still must be compared to loads calculated from specific bridge's influence lines as currently they are only for a case when maximum stresses are achieved with whole deck.

For each highway and lane combination 35 loads were calculated. Loads calculated from A1 data are presented in Figure 2 and Figure 2, loads from A3 – in Figure 15 and Figure 16, also Table 5 shows all of the loads. Scenario 7 was omitted from all figures due to visibility reasons.

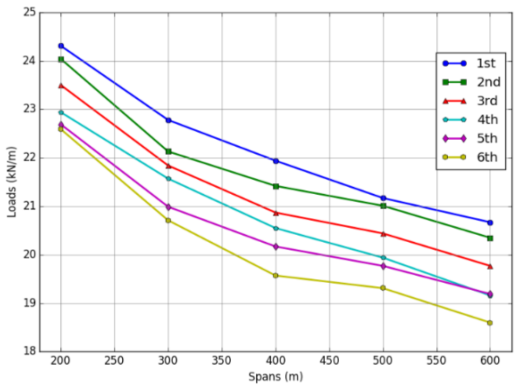

Figure 12. Calculated loads for highway's A1 Lane 1.

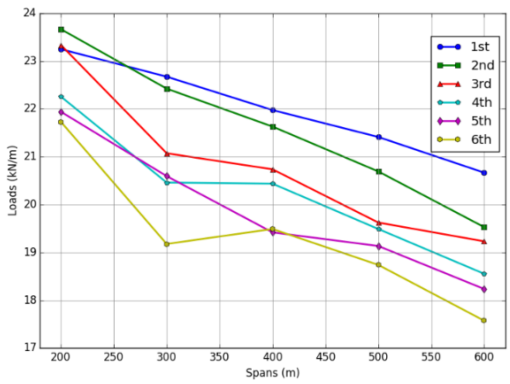

Figure 15. Calculated loads for highway's A3 Lane 2

In this study comprehensive WIM data cleaning was performed based on four different types of filters. Then cleaned data were used to calculate uniformly distributed loads for 200, 300, 400, 500, 600 meters long bridges spans were calculated.

Load values decrease with an increase in bridge span and a decrease in amount of trucks in traffic flow, although there are some exceptions. They could have arisen because cars that were included in the traffic flow was selected randomly but chronological order was preserved, it is therefore possible that cars have been included in the middle of a long truck platoon, that has been preserved in other scenarios.

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These calculated loads still must be compared to loads calculated from specific bridge's influence lines as currently they are only for a case when maximum stresses are achieved with whole deck.

2. To develop damage localization methods for structural elements	Method for damage localization in beam-type structural elements

In the report period studies of experimental evaluation of dynamic parameters (vibration frequencies, modes, damping etc.) for beam-type structural elements and their application to structural health monitoring were carried out. By using appropriate signal processing techniques, dynamic parameters were used for identification of damage – related parameters, such as localization and size of damage, in structural elements. A Wavelet Transform (WT) technique is proposed as a solution to this problem. WT is a mathematical transformation, which represents a correlation between a tested signal and a wavelet function. In case of large correlation, large magnitude WT coefficients are obtained. Largest peaks in plots of WT coefficients vs coordinate of a structure reveal the location of damage. To improve the confidence of algorithm proposed above, a large set of combinations was tested, including all possible wavelet functions at different scale parameters.

In the frame of damage identification algorithm, WT method was compared to the well-known Mode Shape Curvature Squares (MSCS) method, which is based on the fact that a mode shape curvature of a healthy structure is smooth. This smooth surface is obtained through damaged structure's mode shape curvature approximation with a Fourier series functions. The identification of damage was characterized with a so-called Damage Index (DI), which, in case of WT, is equal to the value of WT coefficients, but, in case of MSCS – with an absolute value of difference between squares of mode shape curvature of a damaged structure and its approximation with a Fourier series function. After calculation of DI for every mode shape, this result was normalized to the largest value of DI and summed up for all modes considered in the study. By using the statistical hypothesis approach, DI was standardized, thus yielding a Standardized Damage Index (SDI) and a threshold of 1.28, 2 and 3, corresponding to damage detection confidence of 90%, 95 % and 99%, respectively, was applied. Thresholding of SDI was performed in order to truncate smaller SDI peaks that are misleading in terms of damage location. To quantify the goodness of damage identification for every wavelet, an additional term, called Damage Estimate Reliability (DER) was calculated. DER represents the average cumulative SDI value in the zone of damage divided by this value in 3 zones – zone before damage, zone of damage and zone after damage. DER result is expressed in percentage. WT method requires the analysis of wavelet function performance (in terms of DER) at every scale, thus finding the optimum scale that yields the best damage identification results, therefore an extensive study of DER vs scale behaviour for different wavelets was conducted. An additional study of the influence of number of mode shape input data points on DER values was performed. This was done in order to estimate the density of embedded sensor grid in a real time situation if structure was equipped with one.

Mode shapes were also numerically simulated in FEM commercial software ANSYS. Geometry and material properties of tested samples were taken onto account. Zone of damage was simulated by reducing the thickness of the sample. Experimentally measured signals naturally contain some level of noise, therefore, in order to assess the sensitivity of methods to noisy experimental data, numerical mode shapes were corrupted with an artificial noise of different intensity levels.

WT and MSCS methods were tested on the following samples:

1. two aluminium beams of different length, containing single mill-cut damage;
2. the same two aluminium beams, containing 2 sites of mill-cut damage;
3. two polymer composite beams of different length, containing single low-velocity impact damage.

All calculations, including DI, SDI, DER, etc. for both methods were performed using MATLAB software.

Task for Period 1	Main results
1. Data generalization for development of design procedure for load-bearing elements from cross-laminated timber.	The data were generalized for the plates from cross-laminated timber subjected to flexure and compression with the bending. The model of initial member of transversal load-bearing timber walls was developed.

The data were generalized for the plates from cross-laminated timber subjected to flexure and compression with the bending to obtain necessary information for the development of design procedure for load-bearing elements. Efective strength and stifness method and transformed sections method were considered for the purposes. The both methods were compared analytical and by the experiment. Two cross-laminated timber plates with the dimensions 2X1 m and total thickness in 95 mm were considered. External and internal layers were made from the timber boards with the dimensions 25x50 and 45x195 mm, correspondingly. Fiber direction of the external layers is parallel to the longitudinal axis of the plate. Fiber direction of the internall layer is oriented under the angle equal to 90° to the longitudinal axis of the plate. The layers were glued together by the polyurethane glue under the pressure in 400 kg/m^2. Pine wood with the strength class C18 is considered as a board material. A freely supported beam, which is loaded by the uniformly distributed load, was chosen as a design scheme for both plates, because this statical scheme is widely used for CLT plates in practice. A span of freely supported beam was equal to 1.9 m. the both plates were statically loaded by the uniformly distributed load, which changed within the limites from 1 to 7.5kN/m^2. Considered pannels were analysed by the programs REFM 5.0 and ANSYS v14.

Investigation of rational structure of multy-storey timber buildings was started. Behaviour of light timber framework of three-storey buildings were analysed by the procedure of LVS EN 1995-1-1. Procedure for evaluation of stifness of timber multystorey framework in case of transversal load-bearing wall using was suggested. Framework of initial member of transversal load-bearing timber walls, which is made of pine wood with the strength class C24, was considered as an example. Dimensions of the framework elements are 70X195 mm and 45X195 mm.

In case of non-fulfilment provide justification and describe further steps planned to achieve set targets and results

The planned targets of the NRP IMATEH Project 3 „ *Risk consideration for safe, effective and sustainable structures"* were fully achieved in the reporting period from

01.11.2014 till 31.03.2015. The planned tasks are completed and the main results obtained.

2.3. Description of gained scientific results
(Describe scientific results achieved during reporting period, give their scientific importance)

Target of Project 3: *Develop new methods of risk assessment for buildings and structures to ensure their safe, efficient and sustainable operation.*

Target of the national programme and this project is to develop new methods of risk assessment for buildings and structures to ensure their safe, efficient and sustainable operation. Targets set for this reporting period are fully achieved.

Core task 1: *Investigation of the dynamic characteristics of Latvian road bridges and determination of their impact on construction reliability, to develop the new methods for assessment of structural risk, reliability and robustness.*

Tasks for the Period 1:

1.1. Modeling of bridge and vehicle interaction, taking into account the type of the vehicle, type of the span structure, and pavement eveness.
1.2. Development of method for prediction of live load action combinations.

Investigation presents analysis of dynamic effects obtained from dynamic load testing of city highway bridges in Latvia carried out from 2005 to 2012. 9 prestressed concrete bridges and 4 composite bridges were considered. 11 of 13 bridges were designed according to Eurocodes but two according to SNIP codes. The dynamic properties of bridges were obtained by heavy vehicles passing the bridge roadway with different driving speeds and with or without even pavement. The obtained values of DAF and bridge natural frequency were analyzed and compared to the values of built-in traffic load models provided in Eurocode 1. The actual DAF values for even bridge deck in most cases are smaller than the value adopted in Eurocode 1. Vehicle speed for uneven pavements significantly influence DAF values.

Obtained results show that for bridges road surface condition is a very important factor. If road condition is very bad and with many bumps, then heavy traffic driving with low speed can cause a lot of damage.

Overall DAF values for even pavement were within 1,0 and 1,4 and are smaller than assumed in Eurocode 1.

Bridge natural frequency did not correlate with bridge span and vehicle weight, however for higher natural frequency values DAF values were smaller.

Traffic load models available in structural codes are most often developed for short or medium span bridges, but most unfavorable traffic situations for long span bridges are very different from the ones considered in them. For this reason, funds may be used irrationally, if inappropriate traffic load models are used for long span bridge design.

Weigh – in – Motion (WIM) data from WIM station installed on 72. kilometer of highway A1, have been used in these paper. First data cleaning was performed, then data were split into two lanes. Long span bridge loads were calculated by using information about vehicles found in traffic flow from the cleaned WIM data. Load model calculations were done for 200, 300, 400, 500 and 600 meter long spans.

Traffic flow was simulated using seven different traffic scenarios, out of which first six simulates traffic with varying percentage of trucks. The seventh scenario simulates traffic flow consisting entirely out of cars. For each lane, span, traffic scenario combination Gumbel's distributions were fitted to the highest 30% of the calculated loads, by using the maximum probability estimates for left truncated data; loads were extrapolated to the probability of exceedance of 10% in hundred years period. Results show that Eurocode 1 part 2 load model 1 load is too conservative for use in long span bridge design even when the very unlikely scenario of only trucks in the leftmost lane is considered.

Core task 2: *Development of the methodology for experimental acquisition of dynamic characteristics (modal frequencies, mode shapes, modal damping) of structural elements with the presence of damage (different failure modes) for structural health monitoring;*

Task for the Period 1: *To develop damage localization methods for structural elements.*

According to the Core task 2 of the project: "The development of methodology for experimentally measured dynamic parameters (vibration frequencies, vibration modes, vibration damping coefficients) of healthy or damaged (various forms of material degradation) structural elements and its application to structural health monitoring", the planned objectives are fully met.

A damage identification method, based on vibrational response of a structure, is meant for practical applications. The proposed methodology implies the localization of damage site, which is not seen with a naked eye in homogeneous, as well as in composite materials. Damage Indices were calculated for 1-dimensional and 2-dimensional space to ensure the identification in damage for beam-type and plate-type structures, respectively. It is possible to extend the method to large scale structures, for example, automotive and aerospace structural elements by using the appropriate experimental equipment.

Core task 3: *To develop innovative smart structure with using of removable natural resources with the increased durability and reliability for structural and infrastructural purposes**.***

Task for the period 1: Data generalization for development of design procedure for load-bearing elements from cross-laminated timber.

The data and information were generalized to develop design procedure for load bearing elements from cross-laminated timber subjected to flexure and compression with the bending.

The considered design procedure is based on the LVS EN 1995-1-1, effective strength and stifness and transformed section methods. The effective strength and stifness and transformed section methods were checked analytical and by the experiment. Two cross-laminated timber plates were analysed by the FEM, which was realised by the programs REFM 5.0 and ANSYS v14. It was stated, that the diference between the effective strength and stifness and transformed section methods does not exceeds 20%.

Behaviour of light timber framework of three-storey buildings were analysed by the procedure of LVS EN 1995-1-1. Procedure for evaluation of stifness of timber multystorey framework in case of transversal load-bearing wall using was suggested and checked analytical by the program ANSYS v15.

2.4. Further research and practical exploitation of the results

(Describe further research activities that are planned, describe possibilities to practically exploit results)

For the 2nd period are planned following activities:

Core task 1:

1. Development of method for assessment of new bridge dynamic characteristics;
2. Development of method for prediction of traffic load action combinations.

In the development of the method will be used a computer software to simulate the dynamic behavior of the bridge. Results will be compared to the live-scale dynamic test results. Frequencies of traffic load actions will be analysed and mathematical basis of combination probability will be developed based on obtained theoretical probability models.

Core task 2:

The task for the Period 2 is "Study of damage zone configuration and localization method", which is directly related to studies of the Period 1. A submitted paper to internationally indexed journal is defined as a result of the Period 2. The Period 2 of the project will be devoted to development of dynamic parameter identification experimental methodology in plate-type structures, as well as development of corresponding damage identification algorithm in MATLAB: it is intended to use a 2-dimensional Wavelet Transform algorithm for damage identification over plate coordinates of length (X) of and width (Y). The result is a 3-dimensional map, where Z axis depicts a Standardized Damage Index, obtained from Wavelet Transform coefficients.

Core task 3:

The following activities are planned during the period 2 of the project to achieve the core task 3 targets,

- Development of design procedure for load-bearing elements from cross-laminated timber.
- Experimental check of developed design procedure for load-bearing elements from cross-laminated timber.

Using of transformed section method for load bearing elements from cross-laminated timber, subjected to flexure and compression with the bending, with the different design schemes, must be checked analytical and by the experiment during the period 2 of the project. Cross-laminated timber plates which are suspended in the corners and freely supported by two sides, should be considered under the statical load
Investigations of rational structural solution of innovative smart structure should be started during the period 2 of the project. Rational parameters of prestressing of load bearing cable structure must be evaluated to improve the distribution of internal forces and decrease materials consumption. Saddle-shaped cable roof with the rigid support contour and dimensions 60X60 in the plan must be considered for the purpose.

2.5. Dissemination and outreach activities

(Describe activities that were performed during reporting period to disseminate project results)

In the project Period 1 of the Project „ Develop new methods of risk assessment for buildings and structures to ensure their safe, efficient and sustainable operation" were prepared:

Conference abstracts or publications submitted:

1. Paeglite I., Paeglitis A., Smirnovs J. (2015) The Dynamic Amplification Factor for bridges with span length from 10 to 35 meters. // Journal Engineering Structures and Technologies, 2015, pp.1-8 10.3846/2029882X.2014.996254;
2. Paeglite I., Paeglitis A. (2014) Dynamic Amplification factors of some city bridges, ICSCE 2014: XII Interantional Conference on Structural and Construction Engineering, London, United Kingdom, 22-23 December 2014;
3. Freimanis, A., Paeglītis A. (2015) Modeling of traffic loads for bridge spans from 200 to 600 meters.// The Baltic Journal of Road and Bridge Engineering 10 (3);
4. R. Janeliukstis, S. Rucevskis, M. Wesolowski, A. Kovalovs, A. Chate, Damage identification in beam structure using spatial continuous wavelet transform, IOP Conference Series: Materials Science and Engineering;
5. R. Janeliukstis, S. Rucevskis, M. Wesolowski, A. Kovalovs, A. Chate, Damage identification in beam structure using mode shape data: from spatial continuous wavelet transform to mode shape curvature methods, International Journal of Mechanical Sciences;
6. R. Janeliukstis, S. Rucevskis, M. Wesolowski, A. Kovalovs, A. Chate, Damage identification in polymer composite beams using spatial continuous wavelet transform, Key Engineering Materials;
7. A.Vilguts, D.Serdjuks, L.Pakrastins "Design Methods of Elements from Cross-Laminated Timber Subjected to Flexure". Raksts pieņemts publicēšanai starptautiskas konferences "International Scientific Conference - Urban Civil Engineering and Municipal Facilities", 2015, 18.03.15. – 20.03.15., Sanktpēterburga, Krievija;
8. A.Stuklis, D.Serdjuks, V.Goremikins „Materials Consumption Decrease for Long-span Prestressed Cable Roof". Raksts iesniegts publicēšanai 10. starptautiskās zinātniski praktiskās konferences „Vide. Tehnoloģija. Resursi" (Rēzeknes Augstskola, Rēzekne, Latvija, 2015. gada 18. – 20. jūnijs) rakstu krājumā;
9. A.Vilguts, D.Serdjuks, V.Goremikins "Design Methods for Load-bearing Elements from Cross-laminated Timber", 2nd International Conference „Innovative Materials, Structures and Technologies", 30. septembris – 2. oktobris, 2015, Rīga, Latvija;
10. A. Hirkovskis, D.Serdjuks, V.Goremikins, L.Pakrastins "Behaviour analysis of load-bearing aluminium members "Инженерно-строительный журнал", 5 (57), 2015.

Finished bachelor theses:

1. R.Ruža "Stīgbetona siju nestspējas izpēte" (supervisor Prof. A.Paeglītis);
2. R.Martinsons "Ilgtspējīgas koka tiltu laiduma konstrukcijas" (supervisor Prof. A.Paeglītis);

3. M.Jansons “Ceļa zīmju un apzīmējumu izmantošanas efektivitātes analīze” (supervisor Prof. J.Smirnovs).

Finished master these:

1. Virbule, „Load-bearing elements' behaviour analyse for three-storey timber framework buildings”(supervisor Dr.sc.ing. prof. D.Serdjuks).

Preparation of a doctoral thesis:

1. Ilze Paeglīte “The influence of traffic load on on the bridge the dynamic properties”, scientific supervisor – prof. Dr.sc.ing. Juris Smirnovs, planned to defend in 2017.
2. Andris Freimanis „ Risk consideration for safe, effective and sustainable bridge structures”, scientific supervisor – prof. Dr.sc.ing. Ainārs Paeglītis, planned to defend in 2018.
3. A.Vilguts „Rational structure of multy-storey buildings from cross-laminated timber”, supervisor D.Serdjuks, planned to defend in 2018.
4. Rims Janeliukštis „ The develpment of the damage indentification methods for monitoring of the technical condition of the structure”, scientific supervisor – prof. Dr.sc.ing. Andris Čate, planned to defend in 2018.