TG1 – Sub-group for Module 1: Out-of-plane failure of URM walls

Plan of Approach for phase 3

The current Plan of Approach (PoA) is formulated on the basis of the draft document presented on November 1st 2019 [1], and following the discussions in the general meetings of Task Group (TG) 1, as well as the meetings of a small work group composed by (TU Delft), (BORG) and (Hageman). Recent additions from Michel Kortenaar (VIIA, received 12-03-2020) and (Arup, received 20-03-2020) are also included.

The work of "Module 1: Out-of-plane failure of URM walls" is divided into four main sub-modules:

1. Out-of-plane resistance of three- and four-side restrained walls.
2. Secondary spectra for the determination of the out-of-plane demand on URM walls.
3. Interaction between in-plane and out-of-plane behaviour of the walls.
4. Calibration of NLKA for one-way bending walls against experimental shake table tests.

With respect to the draft of November 1st 2019, this PoA does not include the investigation of the out-of-plane capacity of gables since it has been evaluated of lower priority, and due to lack of time capacity of the parties involved.

A preliminary list of references classified for topic is included in [2]. A first description of the sub-modules 1-3 is provided in [3].

A concise PoA inclusive of expected elapsed time and worked hours is presented for each sub-module.

The total number of expected working hours is summarised in section 5.

1. OUT-OF-PLANE RESISTANCE OF THREE- AND FOUR-SIDE RESTRAINED WALLS

The work for this sub-module aims at the formulation of a consistent procedure to assess the out-of-plane capacity of walls restrained on three or four sides. The current version of NPR 9998 [4] already allows to compute the resistance of the walls based on two-way bending mechanisms, but it does not provide any specific recommendation. It is then suggested to adopt either the approach presented in the Australian standard AS 3700 [5] and further refined by later works [6], [7] or the yield line theory recommended in Eurocode 6 (EN 1996-1-1 and National Annex). To define the applicability of each method, the prediction of the out-of-plane capacity computed according to the different methods is compared against experimental tests. Once that a suitable approach is identified, the method is described and tables and/or plots that facilitate the application of the proposed formulation as well as a calculation example are produced.

The work of the submodule is divided in the following tasks:

1. Review available literature;
2. Definition tensile strength masonry bricks and elements;
3. Comparison between different assessment methods and validation against experimental tests;
4. In-plane/out-of-plane interaction for out-of-plane bending resisting mechanisms with three- and four-side restrained walls;
5. Draft of the background report for update of Annex H (regarding the part of Annex H related to this sub-module);
6. Revision of the background report after comments of TG1;
7. Draft of calculation examples;
8. Creation tables/plots for application of the proposed formulations.

Table 1 presents the expected elapsed time and worked hours for each task of this sub-module.

Table 1. Summary of the tasks of sub-module 1. For each task the elapsed time and the expected worked hours are listed.

Task	2020						Expected worked hours*			
	Jan	Feb	Mar	Apr	May	Jun	TU Delft	BORG	Hageman	RHDHV
1							0	0		
2							80	0		
3							160	40	8	
4							40	80	8	
5							80	40		
6							20	20		
7							80	80		
8							40	20		
Total							**500**	**280**	**16**	**202**

* the hours for the work completed in 2019 are not included in this table

2. SECONDARY SPECTRA FOR THE DETERMINATION OF THE OUT-OF-PLANE DEMAND ON URM-WALLS

The work for this sub-module aims at the formulation of secondary spectra which can be used for the out-of-plane assessment of unreinforced masonry walls when the assessment is not directly captured in a seismic assessment model of an existing building. The formulation which is currently included in Annex H showed large discrepancies with the full-scale house experiments (see commentary EU-Centre [7]). Therefore, an adjustment of the formulation is desired.

It is suggested to change the methodology in the NPR. A tiered approach for the secondary spectra is therefore suggested, as follows:

- Tier 1: code spectrum
- Tier 2: building specific secondary spectrum method

For **tier 1**, different secondary spectra from existing Standards (or Building Codes) will be discussed and compared to each other and to existing studies and literature [10], [11]. The existing methods will then be compared to the EU-Centre full-scale experiments. Based on these comparisons a proper existing secondary spectrum from an existing Standard will be selected for the tier 1 (code spectrum) method. This spectrum will be included in the "wijzigingsbladen" as tier 1 and therefore be ready at the end of march 2020. The activities for this phase are the tasks 1 to 3 from the list below. The deliverable will be a proposal of a secondary spectrum from existing Standards with a background document at the end of march.

The research and methodology of [10] and [11] to determine building specific spectra is used for the definition in **tier 2**. To refine this methodology, the study in [10] will be extended to investigate the impact of different spectra (groundspectrum and floorspectrum, or different floorspectra). This will be done in tasks 4 to 6 from the list below. It is meant to publish the tier 2 (building specific spectrum method) in de the final NPR 2020 and not in the "wijzigingsbladen" and will be ready at the end of June 2020. The deliverable will be proposal how to define a building specific secondary spectra, a background document and a calculation example.

The work of the submodule is divided in the following tasks:

1. Total budget of TU Delft for 2020, mainly for meeting and reviews (based on draft for Phase 3b and capacity TU Delft).
2. Development of general method for secondary spectra (code spectrum & building spectrum).
3. Comparison with EUC-tests & theory.
4. MDOF single storey building (incl. OOP wall).
5. MDOF 2-storey building (incl. OOP wall).
6. Comparison of secondary spectra with NLTH-buildings of Arup.

7. Draft of the background report for update of Annex H (regarding the part of Annex H related to this sub-module).
8. Review of the background report.
9. Draft of calculation examples.

The bullets 4, 5, and 6 are part of the consolidation of the research for the secondary spectra, used for the definition of the building specific secondary spectra of tier 2.

Table 2 presents the expected elapsed time and worked hours for each task of this sub-module.

The bullets 4, 5, and 6 are part of the consolidation of the research for the secondary spectra, used for the definition of the building specific secondary spectra of tier 2.

Table 2. Summary of the tasks of sub-module 2. For each task the elapsed time and the expected worked hours are listed.

Task	2020						Expected worked hours*		
	Jan	Feb	Mar	Apr	May	Jun	TU Delft	BORG	Arup
1							200	0	0
2							0	60	0
3							0	80	0
4							0	440	0
5							0	435	0
6							0	40	240
7							0	0	40
8							0	20	40
9							0	80	0
Total							**200**	**1155**	**320**

* the hours for the work completed in 2019 are not included in this table

3. INTERACTION BETWEEN IN-PLANE AND OUT-OF-PLANE BEHAVIOUR OF THE WALLS

The work for this sub-module aims at identifying when the interaction between the in-plane and the out-of-plane mechanisms may lead to unconservative results if NLPO and NLKA methods are used to assess the seismic vulnerability of the structure. The goal will be obtained by proposing simple models that accounts for how the resisting mechanisms in one direction can affect the capacity in the transversal direction.

The work of the submodule is divided in the following tasks:

1. In-plane/out-of-plane interaction for bending resisting mechanisms with 3 or 4 side restrained walls[1].
2. In-plane/out-of-plane interaction for 1way bending resisting mechanisms.
3. Provide text for the NPR concerning in-plane/out-of-plane interaction.

Table 3 presents the expected elapsed time and worked hours for each task of this sub-module.

There will be no document or study made as a deliverable for this topic. Only text in the NPR will be provided if necessary.

Table 3. Summary of the tasks of sub-module 3. For each task the elapsed time and the expected worked hours are listed.

Task	2020						Expected worked hours*		
	Jan	Feb	Mar	Apr	May	Jun	TU Delft	BORG	Hageman
1							0	0	0
2							40	0	0
3							20	20	20
Total							60	20	20

[1] The IP/OOP-interaction for 2-way bending resisting mechanisms is already covered in part 1.

4. CALIBRATION OF NLKA FOR ONE-WAY BENDING WALLS AGAINST EXPERIMENTAL SHAKE TABLE TESTS

The work for this sub-module aims at studying the dynamic instability displacement and assess whether the formulation currently provided for one-way bending walls is appropriate or should be revised. This is based on numerical nonlinear time history analyses of single degree of freedom (SDOF) systems.

The work of the submodule is divided in the following tasks:

1. Using the results of the models in section 2, points 4 and 5 (or other simplified models) for determining the numerical point of instability.
2. Compare the numerical results with the shaketable tests of unreinforced masonry walls loaded out-of-plane from EU-Centre and/or BuildinG.
3. Checking the factor for what the allowable dynamic instability should be for the Netherlands being cognisant of the very high to extremely high URM slenderness ratios encountered.
4. Provide text for the NPR concerning the maximum displacement.

Table 4 presents the expected elapsed time and worked hours for each task of this sub-module. There will be no document or study made as a deliverable for this topic. Only text in the NPR will be provided if necessary.

Table 4. Summary of the tasks of sub-module 4. For each task the elapsed time and the expected worked hours

Task	2020						Expected worked hours*		
	Jan	Feb	Mar	Apr	May	Jun	TU Delft	BORG	Hageman
1							10	10	10
2							10	10	10
3							10	10	10
4							10	10	10
Total							**40**	**40**	**40**

5. TOTAL EXPECTED WORKING HOURS FOR MODULE 1 OF TG1

The total work planned for Module 1 of the TG1 is given by the sum of the previous sub-modules with the time estimated to support NEN for the update of Annex H on the basis of the background documents produced in the different sub-modules.

The total number of expected working hours for Module 1 is therefore:

This a total of hours, including review, participating meetings et cetera.

REFERENCES:

[1] (2019). TG1 – Sub-group for Module 1: Out-of-plane failure of URM walls. Plan of Approach for phase 3. Memorandum, 1 November 2019

[2] (2019). List of references used for the update of Annex H in NPR 9998. Memorandum, 10 October 2019

[3] (2019). Minutes of the meeting on 27.09.2019. Memorandum, 30 September 2019

[4] NEN, Nederlands Normalisatie Instituut (2018). NPR 9998:2018 nl. Beoordeling van de constructieve veiligheid van een gebouw bij nieuwbouw, verbouw en afkeuren - Geïnduceerde aardbevingen - Grondslagen, belastingen en weerstanden. Delft, the Netherlands

[5] Standards Australia (2011). Australian Standard, Masonry Structures, AS 3700-2011. Standards Association of Australia, Homebush, Australia

[6] Vaculik, J., Griffith, M.C. (2018). Out-of-plane shaketable testing of unreinforced masonry walls in two-way bending. Bullettin of Earthquake Engineering 16: 2839

[7] Sharma, S., Tomassetti, U., Graziotti, F. (2019). Commentary on Annex H of NPR 9998 (2018). EUCENTRE report. Version 1.0, 21 February 2019

[8] CEN. EN 1998-3 Eurocode 8: design of structures for earthquake resistance, Part 3: assessment and retrofitting of buildings. European Committee for Standardization, 2005

[9] NZSEE, New Zealand Society for Earthquake Engineering. The seismic assessment of existing buildings, Part C8: Seismic assessment of unreinforced masonry buildings. Wellington, New Zealand

[10] Galanakis, N. (2019). Determination of the displacement demand for the out-of-plane seismic response of unreinforced masonry walls for the Groningen Case. MSc thesis, Delft University of Technology

[11] Sullivan, T.J., Calvi, P, Nascimbene, R., Towards improved floor spectra estimates for seismic design, Earthquakes and Structures, January 2013.