Environmental impact of masonry and RC frame structures

A. Puskás, J. Virág, L.M. Moga, H. Szilágyi, M. Bindea and Sz.A. Köllő

***Abstract*—**For the realization of current social and public buildings reinforced concrete frame structures with masonry infill walls are frequently used, as well load bearing masonry walls with reinforced concrete tie-beams and pillars. When establishing the appropriate structural solution generally the cost of the realization, the construction time and the architectural impact of the chosen solution are taken into consideration, often neglecting the environmental impact of the chosen solution. The paper presents a study on a three-storey building having the same architecture, realised in two structural solutions. Life cycle analyses are performed for both structural solutions: reinforced concrete frame structure with masonry infill walls and load bearing masonry walls with reinforced concrete tie-beams and pillars. Results based on the material quantities calculated for both situations are compared. Differences appear in all the main LCA indicators taken into consideration: energy, solid emissions in air and water, natural resources consumption and waste generation. Comparing the results the more sustainable structural solution with less environmental impact can be concluded.

***Keywords*—**structural sustainability, masonry walls, reinforced concrete frame, environmental impact.

I. INTRODUCTION

ENGINEERING is traditionally equivalent to numbers, formulas, equations, diagrams and other measurable units, simplifying the evaluation and comparison of different solutions. Sustainability principles defined by the Brundtland Commission of the United Nations on March 20, 1987 [1] as part of the notion sustainable development, are representing huge challenge for the structural engineering society: even if the statement of the concept is easy to understand, in practice it brings difficulties in the exercise of the engineering profession. In practice of the structural engineering establishing environmental impact reduction measures of structural systems are unfortunately reduced to choosing of more environmental friendly materials, but how can we conclude the proper structural solution with reduced environmental impact? Since environmental impact of structures is not an absolute science, the better and better structural solutions – environmental impact-wise – can be achieved only by comparing different structural solutions [2].

Sustainability by default lays on three pillars, which are not mutually exclusive but can be mutually reinforcing [3], representing nothing else than the reconciliation – or the compromise - of environmental, social equity and economic demands. In establishing of the structural system for buildings engineers are accustomed to utilize the most appropriate structural codes, norms and standards, as well as the essential requirements stated in the Council Directive 89/108/EEC [4], overtaken also by other specific laws. When focusing on the requirements “hygiene, health and environment” and “energy economy” further dilemmas can be face in lack of specific and practical measuring instruments. Concerns of specialists from all around the world from the field of civil and environmental engineering represents a progress in obtaining more sustainable structures with reduced environmental impact, but no generally valid rules can be found yet for the given scope. The ISO 14000 standard family on environmental management [5] provides theoretical tools to identify and control the environmental impact of companies and organizations and to improve their environmental performance, but in practice there are still huge gaps in the realisation of the structural systems with reduced environmental impact. One of the most efficient methodologies for obtaining a sustainable structural system is the impact assessment of the studied structure using Life Cycle Analysis (LCA), emphasized in studies performed by Danatzko and Sezen [6] and others. The life cycle analysis of structures is considering impact of the whole cradle-to-grave and to cradle again circle of the materials, structures and buildings (Fig. 1), regulated by European framework standards EN 15643-1:2010 [7] and EN 15643-2:2011 [8].

This work expresses the concern of the authors to the sustainability, in general, and to the sustainability of the structural systems used for buildings, specifically. The research is conducted as an internal program of the Department of Structures of the Technical University of Cluj-Napoca.

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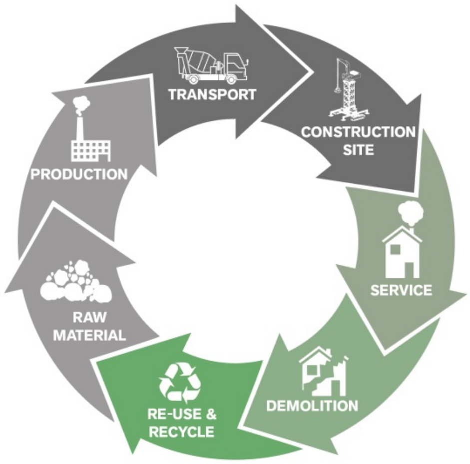

Fig. 1 Life cycle of the construction materials

Environmental impact of a structure is influenced by the established static scheme, the embedded construction materials, the quality and quantity of the used materials, the realisation processes, the service period and eventual maintenance and the possible recycling of the demolished structure. Studies performed by Danatzko, Sezen and Chen [9] Puskas and Virag [10], Naik [11] and others [12][13] are emphasizing that the structural system established in design phase has high influence on the impact of the entire structure, but the embedded materials have the largest influence on the environmental impact of the specific structure.

II. Case study: three-storey building

General dilemma in realisation of current social and public buildings is which type of structure to be used? Reinforced concrete frame structure with masonry infill walls or load bearing masonry walls with reinforced concrete tie-beams and pillars? Differences to be considered are given by the cost of the realization, the available technology and the construction time, the conditions given by the architectural concept, but also the different evolution of the norms ruling the reinforced concrete and masonry structures. Unfortunately environmental impact of structural solution is not yet a current criterion.

For the three-storey building shown on Fig. 2 the same dilemma raised: which structure to be preferred? Since the architecture is simple to be solved by any of the two structural solutions (Fig. 3 and Fig. 4), for the given building the structural differences are given mostly by the differences in the applicable design codes [13] to [2]. For both structural solutions (Fig. 3 and Fig. 4) the same procedure for the design of the complete structure has been performed. It is important to be noticed that also in case of the reinforced concrete frame building for all the external and internal walls masonry has been chosen, even if in some cases lightweight partitioning walls could be used. Since the applicable norms for the design of the structure are different studied situations also important difference in quantities appear. In case of masonry even the wall thicknesses are presenting differences since they are established according to different codes.

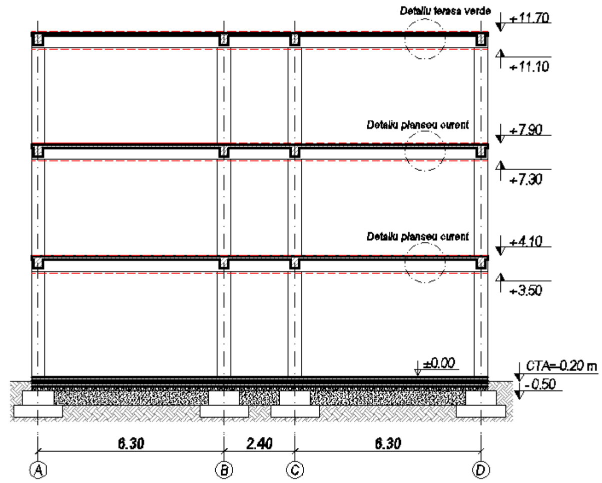

Fig. 2 Floor layout – Masonry bearing walls with RC pillars

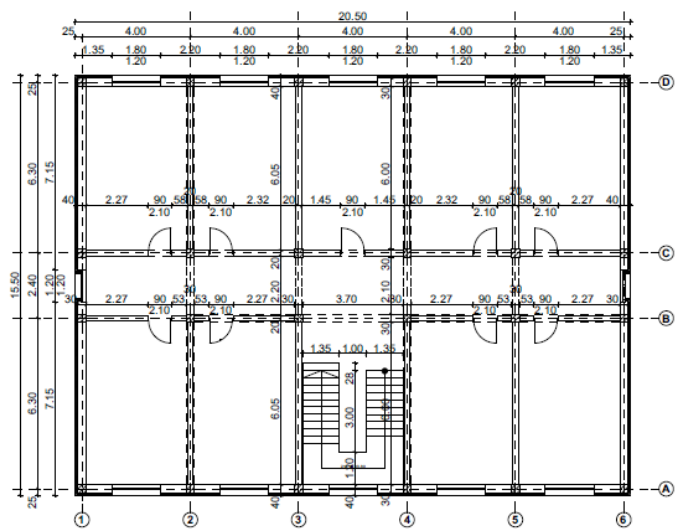

Fig. 3 Floor layout – RC frame structure with masonry infill walls

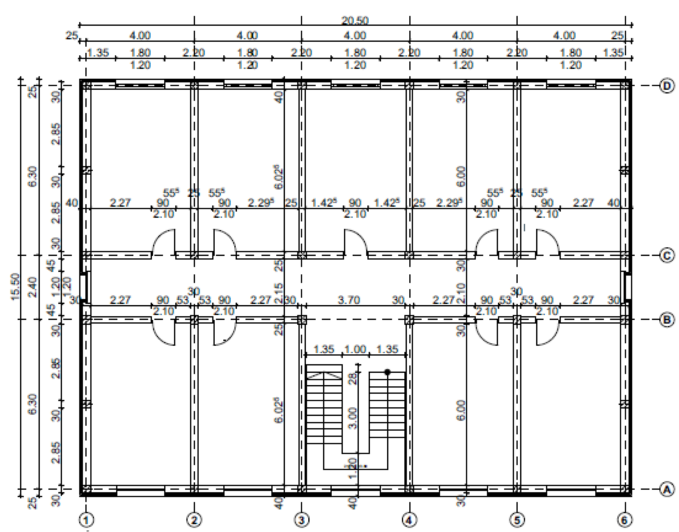

Fig. 4 Floor layout – Masonry bearing walls with RC tie-beams and pillars

The building has been considered to be placed in a seismic area characterised by the upper limit of the period of the constant spectral acceleration branch T_c=0.7 sec and the design ground acceleration a_g=0.15g, corresponding to medium ductility area. For permanent and variable loads the same values have been taken into consideration, including live and wind loads.

Since no material quality influence has been aimed the material qualities for the two cases have been considered unchanged. Quantities of materials obtained for the case 1 (reinforced concrete frame structure with masonry infill walls) are presented in Table I to Table IV. Due to technological differences between the studied structural solutions also the formwork quantity shows important variations.

Table I: Concrete quantities in Case 1

Level	Type	No.	Quant. / type [m^3]	Quantity [m^3]
1	Column	24	0.43	10.26
2÷3	Column	48	0.33	15.84
1÷3	Long. beam	12	1.39	16.68
1÷3	Tran. beam	18	1.65	29.70
1÷3	Slab	3	31.05	93.15
TOTAL				**165.63**

Table II: Rebar quantities in Case 1

Structural element	Quantity [kg]
Longit. beam	2,604.83
Transv. beam	3,852.66
Slab	5,299.46
Column	11,393.48
Total	**23,150.43**

Table III: Masonry quantities in Case 1

Level	Pos.	Thickness [m]	No. levels	Masonry [m^3]
1	Ext.	0.30	1	61.94
	Int.	0.20	1	55.13
2÷3	Ext.	0.30	2	114.41
	Int.	0.20	2	100.51
TOTAL				**331.992**

Table IV: Formwork quantities in Case 1

Level	Type	No.	Quant. / type [m^2]	Quantity [m^2]
1	Column	24	5.70	130.10
2÷3	Column	48	4.44	199.72
1÷3	Long. beam	12	11.10	133.20
1÷3	Tran. beam	18	11.28	203.04
1÷3	Slab	3	310.50	940.50
TOTAL				**1,606.56**

The material quantities for the case 2 are shown in Table V to Table VII.

Table V: Concrete quantities in Case 2

Level	Type	No.	Quant. / type [m^3]	Quantity [m^3]
1	Pillar	24	0.43	10.26
2÷3	Pillar	48	0.33	15.84
1÷3	Tie, long. ext.	6	0.95	5.70
1÷3	Tie, long. int.	6	0.79	4.74
1÷3	Tie, tran. ext.	6	0.72	4.32
1÷3	Tie, tran. int.	12	0.62	7.44
1÷3	Slab	3	40.37	121.10
TOTAL				**169.40**

Table VI: Rebar quantities in Case 2

Structural element	Quantity [kg]
Pillars	7,144.13
Slabs	5,150.00
Transv. tie beams	3,021.85
Longit. tie beams	2,936.78
Horiz. joint	2,955.12
Total	**21,207.88**

Table VII: Masonry quantities in Case 2

Level	Pos.	Thickness [m]	No. levels	Masonry [m3]
1	Ext.	0.30	1	65.85
	Int.	0.25	1	72.98
2÷3	Ext.	0.30	2	122.23
	Int.	0.25	2	133.77
TOTAL				**394.83**

Table VIII: Formwork quantities in Case 2

Level	Type	No.	Quant. / type [m^2]	Quantity [m^2]
1	Pillar	24	4.275 ÷ 1.425	79.80
2÷3	Pillar	48	3.33 ÷ 1.11	124.32
1÷3	Tie, long.	12	6.48	77.70
1÷3	Tie, trans.	18	4.56	82.08
1÷3	Slab	3	310.50	938.00
TOTAL				**1,301.90**

Significant variation of the material quantities can be remarked. Due to the already mentioned technological differences in the construction of the structures the formwork quantity decreases for Case 2 with 23.4%. In similar way also the reinforcement quantity decreases for Case 2 with 9.2% with respect to Case 1, mainly due to the column/pillar and beam/tie beam differences. Even if the size of the pillars and tie beams is lower in Case 2 than the size of the columns and beams in Case 1, due to the excessive imposed minimum thickness of the slab the concrete quantity increases with 2.3% in Case 2 with respect to Case 1. Due to the minimum thickness provision for the load bearing masonry walls also the masonry quantity increases for Case 2 with 18.9% with respect to Case 1.

III. Environmental Impact Assessment Results

For the environmental impact estimation of the structure the Athena Impact Estimator for Buildings life cycle assessment software has been used [21]. The environmental impact estimation of the structural solutions is made by their embedded material. The analysis of the environmental impact considers the same service conditions for the buildings and the same building life expectancy. The analysis has been done using the previously presented material quantities.

The total energy consumption for the studied cases is presented in Table IX and Fig. 5.

Table IX: Total energy consumption comparison

Structural solution	Total Energy Consumption [MJ]
Case 1	4,558,673.01
Case 2	5,212,523.56

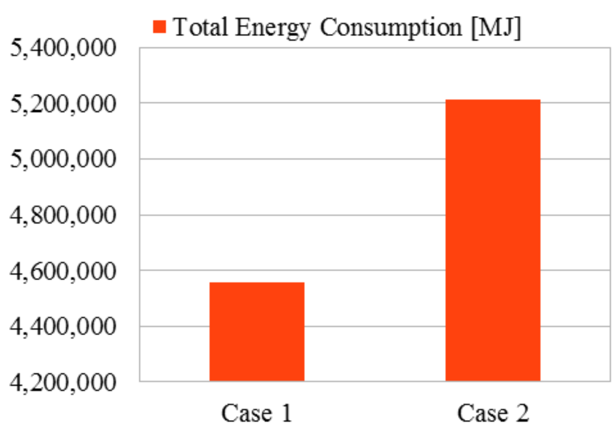

Fig. 5 Comparison of total energy consumption

Table X emphasizes the differences in the solid waste potential of each structural solution. The corresponding graph is shown in Fig. 6.

Table X: Land emissions comparison

Material ID	Case 1	Case 2
Concrete Solid Waste [kg]	8,427.75	8,619.58
Blast Furnace Dust [kg]	246.50	252.11
Other Solid Waste [kg]	21,322.73	25,053.27

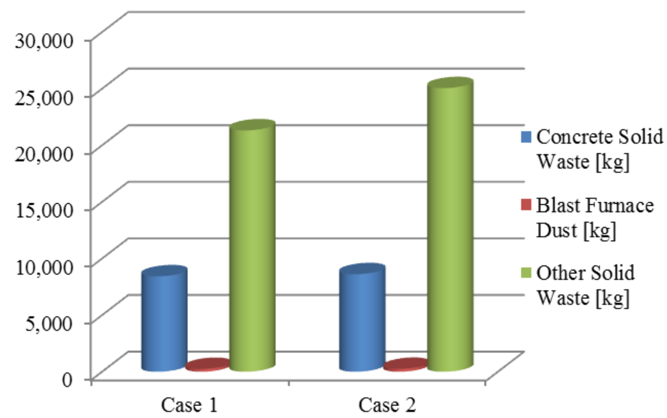

Fig. 5 Land emissions comparison

Quantities of resources used for the studied cases are presented in Table XI. Fig. 6 presents the comparison of the fossil fuel consumption by life cycle stages of the two structural cases.

Table XI: Resource use

Material ID	Case 1	Case 2
Ash kg	241.22	246.71
Carbon dioxide, in air kg	433.78	397.38
Clay & Shale kg	10,900.95	11,149.07
Coal kg	77,857.22	88,169.79
Coarse Aggregate kg	196,172.17	200,637.36
Crude Oil L	12,238.85	13,488.13
Dolomite kg	1,736.96	1,591.21
Ferrous scrap kg	25,750.34	23,589.63
Fine Aggregate kg	144,520.46	147,809.97
Gypsum (Natural) kg	1,694.12	1,732.69
Iron Ore kg	13,316.84	12,225.16
Lignite kg	70.32	64.42
Limestone kg	39,502.54	40,387.65
Natural Gas m3	50,551.85	59,299.90
Sand kg	479.13	490.03
Semi-Cementitious Material kg	5,782.56	5,914.18
Uranium kg	0.57	0.66
Water L	471,366.15	434,424.05

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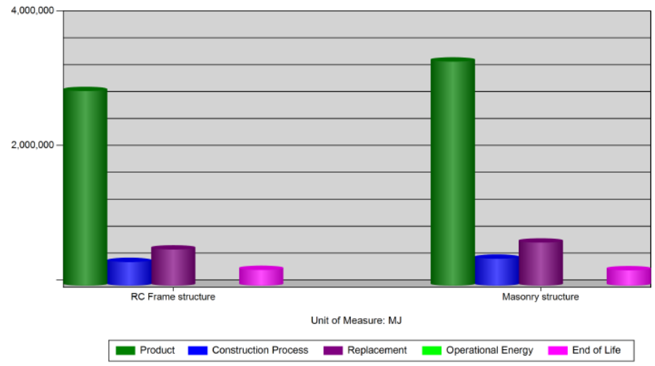

Fig. 6 Land emissions comparison

IV. Conclusion

Even if traditionally load bearing masonry walls with reinforced concrete tie-beams and pillars are considered cost efficient with respect to reinforced concrete frame structures with infill walls, the case study leads to unexpected results: for the given building - considering the same placement, architecture, load conditions, material quantities – the environmental impact of the load bearing masonry wall structure is higher than the impact of the reinforced concrete frame building with masonry infill walls. Since economy of the structural solutions has not been studied results on the sustainability of the structural solutions cannot be concluded.

Sustainability of a structural solution – as well as the environmental impact – depends on the location of the studied building due to the high amount of energy needed for all kind of transportation. The presented study presumed standard conditions for the project location hoping to obtain unequivocal results, but unfortunately –due to design standard discrepancies like minimum slab thickness in case of load bearing masonry walls – the obvious and expected results were not achieved.

In order to establish less environmental impact structural solutions use of the presented assessment procedure for similar structures can be recommended, but results have to be read considering also local conditions.

References

[1] Brundtland, H., "Our Common Future", Oxford University Press, 1987.
[2] Puskas, A., Moga, L.M., "Sustainability of building Relationship between economy and sustainability for a multi-storey reinforced concrete frame structure" WIT Transactions on Ecology and The Environment, Vol. 176, WIT Press, 2013, ISSN 1743-3541, doi:10.2495/ESUS130171
[3] United Nations General Assembly, 2005 World Summit Outcome, Resolution A/60/1, adopted by the General Assembly on 15 September 2005.
[4] Council Directive 89/108/EEC, http://eur-lex.europa.eu/.
[5] ISO 14000 standard family, http://www.iso.org/iso/home/standards/management-standards/iso14000.htm.
[6] Danatzko, J.M., Sezen, H., "Sustainable Structural Design Methodologies" Practice Periodical on Structural Design and Construction, Vol. 16, Issue 4, 2011, ISSN 1943-5576, doi: 10.1061/(ASCE)SC.1943-5576.0000095.
[7] Sustainability of construction works - Sustainability assessment of buildings - Part 1: General framework, EN 15643-1:2010, European Committee for Standardization (CEN), http://www.cen.eu.
[8] Sustainability of construction works - Assessment of buildings - Part 2: Framework for the assessment of environmental performance, EN 15643-2:2011, European Committee for Standardization (CEN), http://www.cen.eu.
[9] Danatzko, J., Sezen, H., Chen, Q., "Sustainable design and energy consumption analysis for structural components" Journal of Green Building: Winter 2013, Vol. 8, No. 1, pp. 120-135., doi: 10.3992/jgb.8.1.120.
[10] A. Puskas, J. Virag, Cost or energy efficiency? Criteria in design of a reinforced concrete structure of a public building, Proc. of the 8th In. Conf. on Energy & Environment, eds. V. Mladenov, T. Tashev, H. Wang, I. Kralov, S. Stankevich, P. Yildiz & J. Burley, Rhodes Island, pp. 112-117, ISBN: 978-960-474-312-4.
[11] Naik T. R., Sustainability of Concrete Construction, CBU-2007-02, ASCE Practice Periodical on Structural Design and Construction, Vol. 13, No. 2, pp. 98-103, 2008.
[12] Struble L., Godfrey J, How sustainable is concrete?, Proc. of the International Workshop on Sustainable Development and Concrete Technology, Ed. K. Wang, Iowa State University, pp. 201-212, 2004
[13] Eurocode: Basis of structural design, EN 1990/1992
[14] Eurocode 1: Actions on structures, EN 1991/1992
[15] Eurocode 2: Design of concrete structures, EN 1992/1992
[16] Eurocode 6: Design of masonry structures, EN 1996/1992
[17] Eurocode 8: Design of structures for earthquake resistance, EN 1998/1992
[18] NP 007-97, Design code for reinforced concrete structures, 1997
[19] CR6-2013, Design code for masonry structures, 2013
[20] P100-1/2006, Earthquake resistance design code – Part I - General design rules for buildings, 2006
[21] Athena Impact Estimator for Buildings 4.5, Athena Sustainable Materials Institute, http://www.athenasmi.org

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