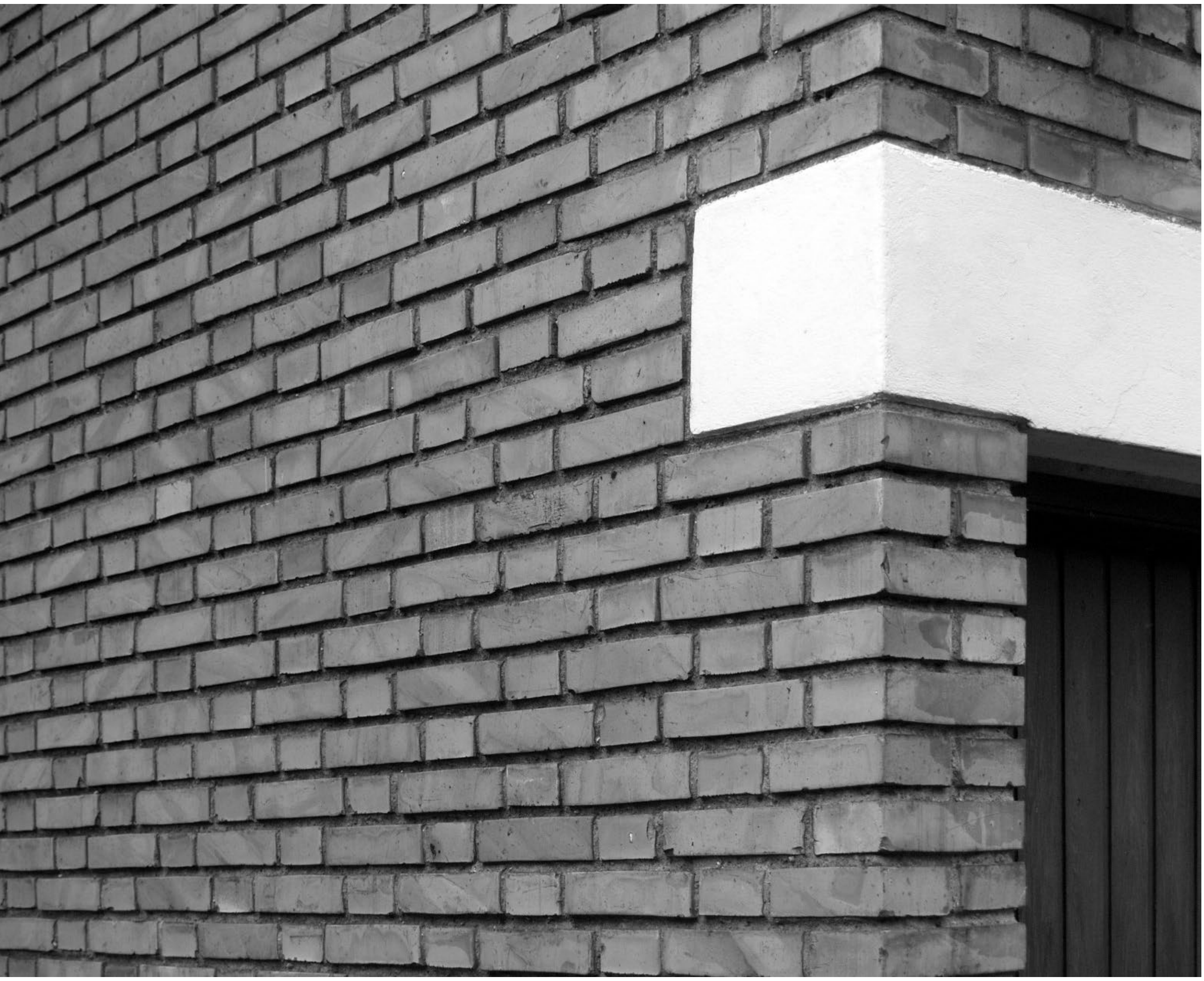

Kingohusene Courtyard Houses, Helsingør/Elsinore, Denmark, 1956-1960, by architect Jørn Utzon. Photographer: Jens Kristian Seier, 2007. Source: https://www.flickr.com/photos/seier/2141693607/in/photostream/ (Wikimedia Commons)

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THE EFFECT OF MASONRY INFILL MODEL SELECTION ON THE SEISMIC RESPONSE OF REINFORCED CONCRETE FRAME STRUCTURES

ABSTRACT

In many countries, reinforced concrete (RC) frames are widely utilized as the primary building structure. The infill is typically composed of traditional masonry (brick elements connected with mortar), commonly without isolation from the frame. It is noted that in engineering practice, seismic force calculations for RC frame buildings are often conducted on models that exclude masonry infill, even when the infill is not isolated from the frame through specific construction elements. In such cases, the walls are considered only as a permanent load. Consequently, the contribution of non-insulated (bonded) masonry infill to changes in bearing capacity, stiffness, and ductility of the RC frame, affecting stresses and horizontal movement during seismic activity, is frequently disregarded. To assess the consequences of prevalent calculation models, four representative types of RC frame models with masonry infill were analysed herein. The study demonstrated that differently conceptualized models of the same building impact dynamic characteristics, including forces and displacements of the main frame structure. The dynamic analysis revealed that inadequate treatment of the frame and non-insulated infill connection in the design phase can lead to dangerous phenomena such as "soft floors," significant torsion, and the effects of short columns going unnoticed. Therefore, this paper underscores the importance of appropriately addressing non-insulated infill in the calculation model in routine design practices. Additionally, it advocates for the issuance of precise instructions for special construction measures that would effectively isolate masonry infill from the frame when such a solution is justified.

Key words: *RC frame buildings, masonry infill, dynamic characteristics, infill stiffness and ductility*

1. INTRODUCTION

In general, when designing buildings in seismically active areas, numerous approximations are typically introduced into analytical models due to many unknowns. This stands in contrast to building design in areas without seismic activity. The question of the correctness (accuracy) of the analytical model in calculation analyses is warranted. To achieve higher "accuracy," it is essential to encompass everything that occurred in the past and evaluate potential events during the building's lifespan. Regulations, standards, professional rules, analytical and experimental research, and engineering knowledge and experience primarily guide us in this endeavour. Simultaneously, the expectation is that building calculations are conducted within a reasonable timeframe, ensuring safety and cost efficiency. Therefore, establishing a high-quality structural conception in the design phase, along with a corresponding calculation model, is crucial.

During calculation analyses, the designer constructs a model representing the actual building structure. Generally assuming the model's adequacy for providing accurate and reliable results, especially with the application of 3D models and modern static and dynamic software packages, often neglects numerous limitations in such analyses. Experienced designers, alongside complex computer calculations, critically review and perform control calculations on simpler models, dividing the structure into logical parts/elements. They also avoid blind adherence to regulations that might be unclear or illogical for a specific case. This approach to computational analyses has proven effective, recognizing that all numerical methods possess advantages and disadvantages, making them inaccurate for all structure types.

The discussion on the "accuracy" of analytical procedures for calculating real construction is justified. Experienced engineers do not rely solely on analytically obtained results but incorporate additional safety measures. The approximation of the structure by mathematical and numerical models, construction methods, execution inaccuracies, material inhomogeneity, etc., confirms that the calculated and actual behaviour of the structure can only approximately align. Building execution occurs in segments, at different time intervals, using heterogeneous and anisotropic materials, whereas calculation models, in practice, consider the building as a whole. Such analyses may not adequately encompass residual stresses, local plasticization, imperfections, crack appearance and propagation, stress redistribution, soil behaviour, and various subsequent phenomena.

In addition to the series of approximations listed above, the simulation of real behaviour becomes more complex when the building is subjected to seismic (dynamic) loading. A rough approximation occurs when seismic load is introduced to buildings. Firstly, the intensity and properties of the future earthquake are unknown, and secondly, seismic forces' intensity is typically derived by reducing the design elastic spectrum specified in regulations. The accuracy of this reduction under specific conditions and the seismic forces' intensity are valid concerns, given that an earthquake is a spatial phenomenon involving the chaotic propagation of seismic waves through the ground, interacting with the building [1].

It is justified to perform seismic impact calculation analyses for completed structures, considering that an earthquake is a load that manifests when the building is in use. However, considering the aforementioned conditions introducing a series of "errors" into the calculations, it cannot be definitively stated that the building will behave as per the calculations or even withstand the predicted earthquake. Therefore, it is reiterated that, for a favourable seismic response, the most crucial aspect is to have a well-conceived building design, incorporating fundamental seismic principles during the design phase. Those basic principles primarily refer to [2]-[4]:

- proper design of the building disposition, in the base and in height (favourable ratio of dimensions, aspiration towards symmetry, increased stiffness towards the bottom of the building, absence of soft floors, proximity of the centre of stiffness and mass on the floors, increased resistance to torsion, no out-of-line dislocation of vertical columns, no short columns in lower floors, etc.);
- proper selection of stiffness, load capacity, and ductility of the vertical structural system, and the use of seismic dividers at discontinuities;
- the use of rigid interfloor structures in their plane, without semi-levels and larger peripheral perforations (preference is given to monolithic RC interfloors in the system with underlays);
- foundation selection in accordance with the characteristics of the soil and structure (for softer soils, preference should be given to foundation slabs and/or rigid grills);
- performing the infill walls in accordance with the calculation model (e.g., isolating the infill from the RC frame if the infill was not included in the analyses).

The structure's stiffness directly affects the magnitude of the horizontal movements of the building in the case of an earthquake. Increasing stiffness limits the second-order adverse effects on the deformed shape of the vertical supporting elements. Limited movements prevent damage to the infill elements, which can realistically occur even in minor earthquakes. The bearing capacity of the structure affects the formation of plastic joints in a strong earthquake. Higher bearing capacity enables the later formation of plastic joints in the elements and allows elements to remain in the linear-elastic area, without excessive damage, in less strong earthquakes. Ductile structures, in strong earthquakes, have proven to be a good choice because, in the process of nonlinear deformation, they absorb seismic energy and prevent brittle fractures and sudden collapse.

It is known that in constructions made of reinforced concrete, satisfactory load-bearing capacity, stiffness, and ductile behaviour can be achieved even in the strongest expected earthquake, especially in regular structures with proper detail shaping and reinforcement. Such monolithic structures, with their multiple static indeterminacy, enable stress redistribution and prevent progressive breakage due to damage to one of its elements/parts. This is of essential importance in preserving the structure's integrity and preventing collapse because the occurrence of damage in the strongest earthquake is assumed in advance. On the one hand, it is not economical to design an ordinary building that would have damage in the main structure and infill elements in weaker earthquakes, while on the other hand, it is not economical to design such a building that would remain completely undamaged in the strongest earthquake.

RC flexible frame structures in seismically active areas must have a limited height (number of above-ground floors) to ensure that horizontal movements remain within satisfactory limits. It is crucial to accurately predict the formation of plastic joints in beams and columns. A viable solution is to initiate the formation of plastic joints first in the beams, then at the base of the columns, with priority given to the columns of the ground floor. Alternatively, it becomes necessary to stiffen the skeleton with reinforced concrete walls. Well-designed, stiffened structural systems of this nature are extensively employed in many countries worldwide, particularly in regions anticipating strong earthquakes.

Masonry infill is primarily utilized for facades and internal space separation in RC frame structures (Figure 1). However, during seismic calculation analyses, the infill is typically omitted from the structural system model and is only considered as an external load per floor. When a building is designed in this manner, it is essential to implement constructive measures to ensure the actual isolation of masonry infill from the main RC structure.

Specific measures must be taken to prevent walls from tipping out of their plane. If the masonry infill is connected to the RC structure, it will inevitably influence the dynamic characteristics of the structure. Simultaneously, the response of a structure with bonded (non-insulated) infill may be more or less favourable compared to a pure skeleton. The possibility of an unfavourable response must be considered and adequately analysed during the design phase to ensure the building's safety against excessive damage or collapse in a timely manner.

Figure 1. RC frame structures with masonry infill: a) unanchored walls; b) walls anchored with vertical cerclages*; c) walls anchored with horizontal and vertical cerclages. Case studies from Banja Luka, Bosnia and Herzegovina. Photography by authors, 2024.*

It is known from practice in our region that infill walls of RC frames are traditionally made with classic masonry blocks connected with mortar, without insulating the infill from the frame (Figure 2a). It is not a rare case that reinforcement anchors are placed in each or every other horizontal mortar joint, which are drilled into the columns. Through this connection, overturning out of the plane is ensured (Figure 2b). Another procedure to prevent overturning is to fasten the walls to the RC frames by means of horizontal and/or vertical cerclages, especially for high floors and/or larger spans (Figure 2c). However, it is not rare in recent practice, even in tall buildings construction, that during the masonry process there is no additional rigid binding of the infill, that is, no anchoring of the infill walls for the basic RC skeleton structure.

Figure 2. Execution of frame infill: a) classic *masonry; b) anchoring; c) with horizontal* cerclage*. Case studies from Banja Luka, Bosnia and Herzegovina. Photography by authors, 2024.*

The load capacity, stiffness, and ductility of the non-insulated infill will certainly affect the behaviour of the RC frame. These influences are not taken into account or are not adequately considered in everyday engineering calculations. The question of the correctness of such calculation procedures arises because they do not correspond to the actual state of frame buildings and affect their behaviour in earthquakes. There is a need to consider analyses with non-insulated masonry infill in addition to the calculation analysis of the RC frame structure without included infill. Modern software can relatively quickly analyse several different structure models, and such an approach should be prescribed and standardized in an adequate form, facilitating the application of such calculation analyses in everyday design practice.

1.1. FRAME AND MASONRY INFILL MODELLING

Regarding the infill characteristics, it should be noted that classic walls are made of masonry elements (blocks) and mortar as a binding material. These are heterogeneous elements/materials with anisotropic properties, i.e., there is a big difference in the behaviour of the walls under pressure, tension, and shear. While the walls, on one hand, can accept significant compressive stresses, on the other hand, their tensile load capacity is negligible, and they have a modest shear load capacity. However, shear resistance largely depends on vertical compressive stresses, and without gravity loading, such stresses are almost non-existent, so the shear capacity of infill walls is relatively low.

As noted, rigidly bonded infill with RC columns can disrupt the expected behaviour of a pure frame structure. Reducing the horizontal displacement of the frame is a favourable contribution of the infill, but the rigid infill, even with large cracks and failure, can damage the columns in the contact zones (Figure 3), because the frames under horizontal load exert great pressure on the infill through their deformation. Such frame stresses cause the effects of compressed diagonals and short (shear) columns. In addition, the different purpose on different floors affects the amount of the infill, and thus its effects. It is often the case that infill is omitted on the ground floor (due to business activity), and that infill is significantly represented in the upper floors (due to residential use). This can cause a soft ground floor effect, which is particularly dangerous. Also, the amount of the infill can be different in specific facades in the building. Street facades are often more open than the rest, which significantly causes asymmetry of the building (increasing the eccentricity of the centres of stiffness and mass) and the appearance of unwanted strong torsion under seismic load.

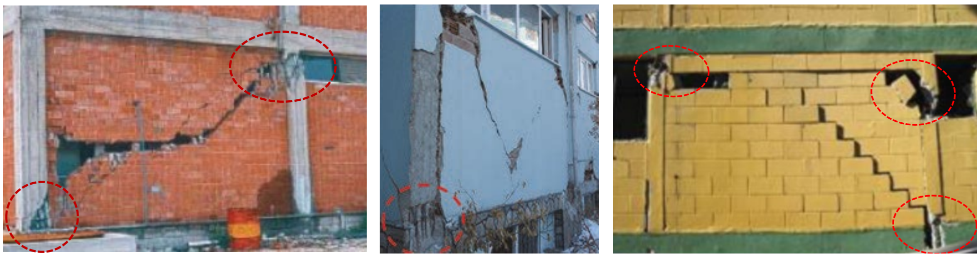

Figure 3. Cracks and crushing of infill and columns in an earthquake as a consequence of mutual action: a) Adana-Ceyhan earthquake 1998 [1]; b) Van earthquake 2011 [1]; c) Chile earthquake 2010 [12].

1.2. OVERVIEW OF CURRENT METHODS

Recent earthquakes in various locations (Petrinja, Croatia, in 2020 [5], Zagreb, Croatia, in 2020 [6], Aegean Sea, Izmir, Turkey, in 2020 [7], Turkey and Syria in 2023 [8], Morocco in 2023) demonstrated significant damage to different building types, especially to brick buildings and masonry infill in RC buildings. Past earthquakes over the last 15 years (L'Aquila – Italy in 2009 [9], Lorca – Spain in 2011 [10], Central Italy in 2016 [11], Albania in 2019 [12]) have also shown that masonry infill in RC frames is highly susceptible to damage. Studies on the earthquake impact on buildings in the 2015 Nepal earthquake revealed that masonry infill notably increases building stiffness [13]. The contribution of masonry infill to the horizontal bearing capacity of RC frame buildings, using sophisticated computational models, was investigated in [14]. The change in the oscillation period of the building structure caused by non-insulated masonry infill, and thus the change in the calculated seismic forces, was discussed in [15]-[17]. Also, in [18]-[21], different behaviour of rigid masonry infill in flexible frames was investigated. In [22], a broader overview of tests on walls for buckling outside the main plane is given, and the interaction of in-plane and out-of-plane forces is discussed in [23]-[25], and the complex behaviour of RC frames in such conditions is indicated. The conducted tests concluded that frame deformation could lead to the detachment of the masonry infill, potentially causing walls to fall out of their plane.

Omitting non-insulated infill in the design phase calculations can lead to unpredictable behaviour in buildings during earthquakes, particularly in those with irregularly arranged infill walls. Such irregularities cause a number of unfavourable effects (torsion, soft floors, short columns, etc.). These problems were pointed out in [26], [27]. In [28], it was pointed out that the induced torsion easily leads to the out-of-plane buckling of the infill walls. In [29], the problem of a soft floor, which appears due to different requirements for space utilization, was discussed, with the conclusion that this phenomenon must be avoided. The problem of the soft floor was also pointed out in [30]. Also, the dangers of short columns due to strong parapet walls appear, which can be a significant problem, as pointed out in [31], and in [32], it was shown that such infill must be isolated (separated) from the RC frame.

With the ongoing evolution of computational models, combined with growing experience and insights into the impact of infill walls on RC frames, a considerable variety of models have been developed, incorporating masonry infill in their analyses. At the same time, the modelling of RC frames with masonry infill can, in general, be divided into two groups: macro-modelling and micro-modelling. Macromodels are intended for the global calculation analysis of the RC framework structure, where the infill is incorporated in an acceptable form, such as an equivalent compressed diagonal. Micromodels are designed to vary a number of parameters, which include the masonry infill and the boundary conditions of the connection with the RC frame. The goal of such micromodels is to capture as realistically as possible the local yielding of the connection between the infill and the frame. It's important to note that there is still no universally accepted consensus on a single approach to these analyses.

The concept of the equivalent diagonal, by which the masonry infill is introduced into the calculation models, dates back to the 60s of the last century, and over time this concept has been perfected (Figure 4) [33]. However, the equivalent diagonal model cannot capture the change in stress along the column, caused by the infill as a panel with a continuous connection to the column [34], [35]. For this reason, cases of different orientation and number of diagonals were analysed (Figure 5), which reduce the lack of continuous connection between the infill and the frame [36]. Also, some authors dealt with defining the stiffness of the diagonals, that is, the force-displacement relationship. In [37], the width of the diagonal was taken as a percentage of its length, and in [38], [39], a more complex method for calculating the diagonal's width is adopted, taking into account factors such as the contact length between the frame and the infill and the relative stiffness ratio between them.

Also, there are proposals for adequate inclusion of infill bearing capacity and the capacity of different types of failure in RC frames for horizontal force action. In [40], it was recommended to include more types of infill failure in the analyses, and in [41], a nonlinear force-displacement connection was proposed, while a trilinear connection was considered in [42], [43]. Also, the hysteresis behaviour of the material was considered, but in this case, there are a number of problems in dynamic nonlinear analyses. One of the most frequently applied models is given in [44], [45], while in [46], an improved model is shown, along with experimental tests, which includes the cyclic behaviour of the equivalent diagonal.

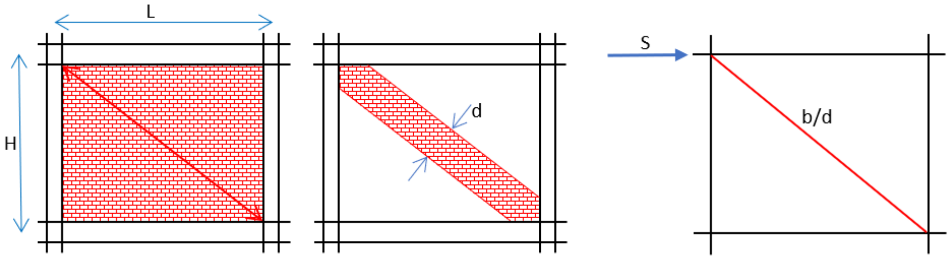

Figure 4. Diagonal action of masonry infill - equivalent pressed diagonal. Diagrams by authors.

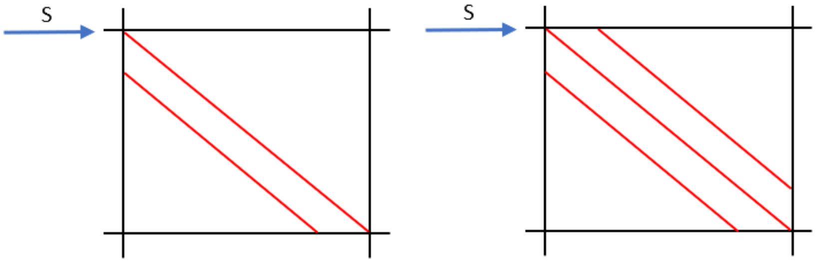

*Figure 5. The **models with a different** number of equivalent pressed diagonals. Diagrams by authors.*

The fact is that there is an interaction of horizontal forces in the plane and outside the plane of the frame, yet this presents a complex challenge for accurate modelling. This issue necessitates further research and validation to develop adequate modelling approaches. Increasing the bearing capacity of the masonry infill in the form of the application of reinforced, instead of ordinary walls [47], [48], or using a textile/wire mesh in the mortar [49]-[51], can be one of the solutions to this problem. Also, the formation of horizontal special sliding surfaces is a procedure that increases the deformability of the infill, while not disturbing the influences in RC frames [52]-[55]. By completely isolating infill walls from RC elements using special inserts, the RC frames can function in a way that allows the infill to be disregarded, because in such a case its activation occurs only after significant deformations of the RC elements. Placing soft material in the joints between the infill and the RC elements is imposed as a more simple solution [56], [57], with the fact that the safety of the infill against falling out of the plane should be ensured. In [58], [59], steel anchors were used for the connection of the infill and RC elements, an examination of such connections was conducted, and appropriate recommendations were given.

It has been established that there's a need to persist in developing and refining solutions for insulating infill, and also to validate these solutions through experimental testing. Although the majority of regulations allow the use of isolated infill, these procedures are still not clearly and widely elaborated, so in practice improvisations can often be seen. The INODIS infill frame isolation system (Figure 6) is based on specially designed details supported by experimental tests and numerical analyses [60], [61]. In the non-linear analyses, the software package SAP2000 and the characteristics of the joints after plasticization was used, in accordance with [62]. In the INODIS models, link elements were introduced to simulate the non-linear behaviour of the equivalent diagonal, and the initial stiffness and stiffness with cracks were determined according to [63]. With such models, different infill configurations were analysed, using the approach from [64], [65].

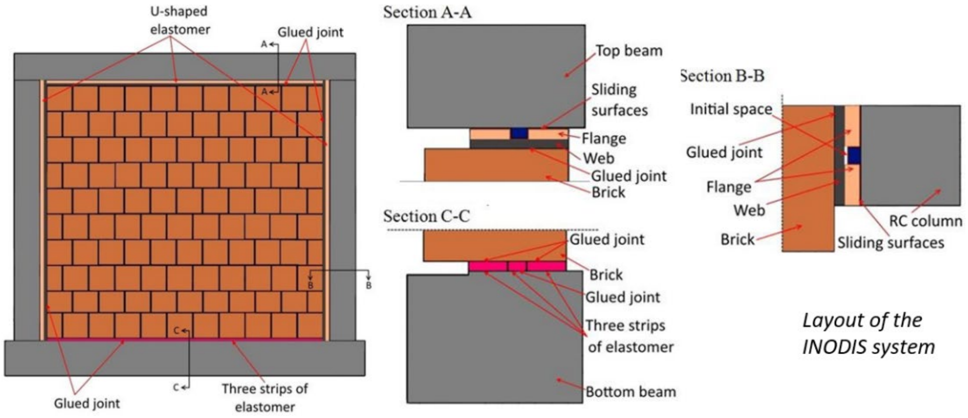

Figure 6. Infill insulation model in the ***INODIS*** *system [61].*

2. SUGGESTIONS OF POSSIBLE INFILL MODELS

The typical patterns of damage and failure for masonry infill within a RC frame's plane usually manifest in one or a combination of the following three ways:

- horizontal shearing (sliding) of the wall along the mortar joint,
- crushing the wall in the corners due to exceeding the bearing capacity in the pressed diagonal direction,
- cracking the wall as a result of exceeding the tensile load capacity perpendicular to the pressed diagonal.

The expected behaviour of the RC frame with masonry infill, when subjected to lateral forces, in the case of the strongest design earthquake, is non-linear in nature, that is, in a short time it transitions from linear to non-linear behaviour. In this paper, four different cases of frame building with masonry infill are included in the analysis (Figure 7):

a) masonry infill continuously bonded with frame – model Ma,

b) masonry infill isolated from the frame, i.e., frame without infill – model Mb,

c) masonry infill modelled in the form of equivalent elastic diagonals that bear only pressure – model Mc,

d) masonry infill modelled in the form of equivalent diagonals with non-linear behaviour, that only bear pressure up to a certain limit – model Md.

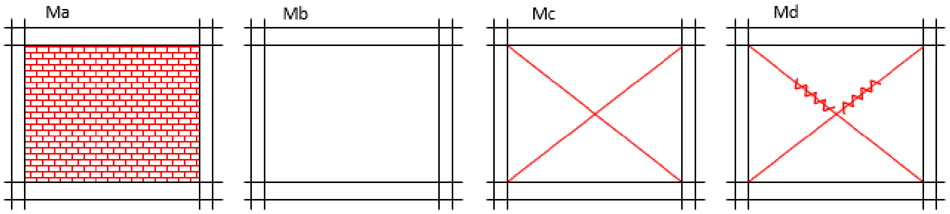

Figure 7. Calculation models of RC frames with masonry infill – Ma, Mb, Mc and Md. Diagrams by authors.

For all cases considered in the analysis, the assumption made was that there is no masonry infill on the ground floor, reflecting a typical design in modern urban multi-story buildings in these areas (Figure 8). These buildings typically have commercial spaces on the ground floor, which are often subject to changes in usage. As a result, these areas usually lack rigid partitions and facade walls. Conversely, the upper floors, designated for residential use, tend to have a higher density of walls, particularly due to the growing demand for smaller apartments.

Figure 8. Typical buildings in Banja Luka (the ground floor for commercial spaces, and the upper floors for residential use). Photography by authors, 2024.

The discussion presented herein aims to highlight the varying responses of RC frames depending on the type of masonry infill model, illustrated through examples of actual buildings. The numerical modelling was conducted using the *Tower8 software* (*Radimpex*, *Belgrade*), which is well-suited for the calculation of multi-story buildings, including brick buildings.

Cracking of concrete and infill walls in seismic analyses, in all models, was introduced through the realistically expected reduction in stiffness, in accordance with the usual recommendations. In the Md model, non-linear connections of equivalent diagonals/rods with the frame are additionally introduced. The non-linearity of the connections is taken in the form of a bilinear diagram (Figure 9) for pressed rods because, in all cases, the rods are prevented from receiving tension.

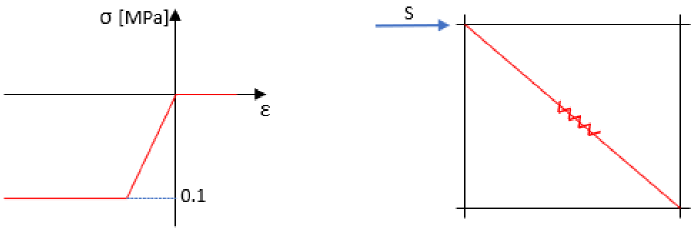

Figure 9. Bilinear elastoplastic working diagram for equivalent diagonals in the Md model. Diagrams by authors.

2.1. SEISMIC ANALYSIS OF ESTABLISHED MODELS

To align with the objective of assessing the impact of masonry infill on the seismic response of the RC frame structures, different numerical models (Ma, Mb, Mc and Md) with different infill-frame connection modelling were illustrated (Figure 7). As an example, the residual building's frame structure was considered, with the ground floor dimensions being 15.0 x 33.0 m, the upper floors' dimensions being 18.0 x 36.0 m, with a total of P_0+P+4 floors, and an overall height of 2 x 4.0 + 4 x 3.2 = 20.8 m. The basement is a rigid structure with extensive RC walls, so the seismic analysis is performed only for the above – ground part H = 16.8 m. Spatial modelling of the structure was performed (Figure 10a), and the relevant section frames were taken for detailed analysis for all models (Ma, Mb, Mc and Md), where the results are better presented (Figures 10b, 11a and 11b). Seismic analysis was performed according to EC8 (Lateral forces method), for ground acceleration $a_{gR}/g=0.25$, soil category B and importance factor II ($\gamma=1$).

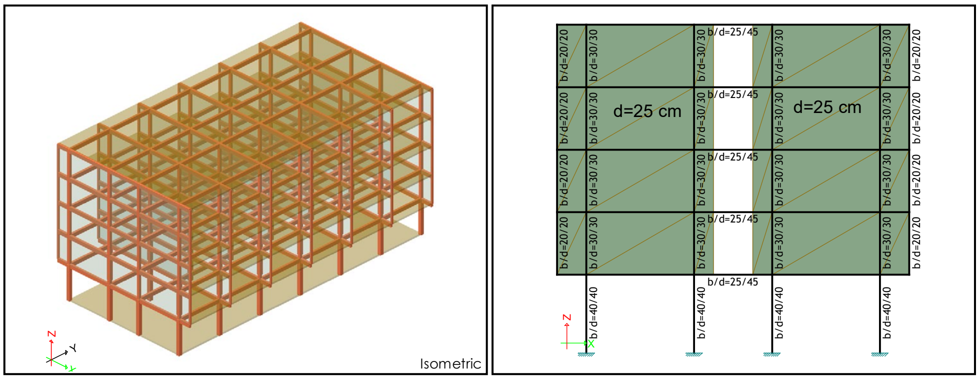

Figure 10. a) Calculation 3D model of the building structure; b) Section frame for model Ma. Diagrams by authors (Radimpex Tower 8).

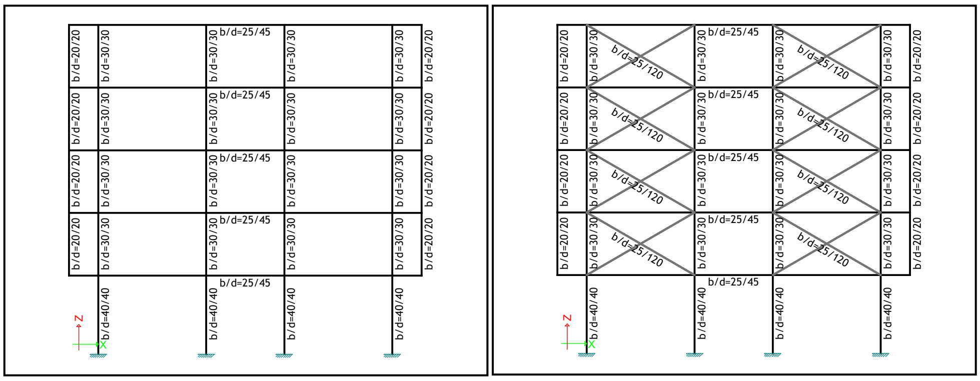

Figure 11. a) Section frame for model Mb; b) Section frame for models Mc and Md. Diagrams by authors, (Radimpex Tower 8).

The dimensions of the columns on the upper floors are w/d=30/30 cm, and on the ground floor are w/d=40/40 cm, to increase the stiffness of the lower floor where the largest stresses are expected. All beams have a cross-section w/d=25/45 cm, while the infill walls have a thickness of d=25 cm (medium class brick). The dimensions of the equivalent diagonal cross-section were taken in accordance with the previously mentioned recommendations, i.e. the width of the diagonal was taken as the value of the wall thickness ($b=d_w=25$ cm), while the height was taken as 25% of the mean value of the length of the diagonal and the height of the frame ($d=0.25\cdot0.5\cdot(h_w+l_d)=0.25\cdot0.5\cdot(320+640)=120$ cm). The diagonals are placed only in case of the walls without openings, where they can be fully activated, that is, only in the two main spans of the frame (Figure 11). Diagonals exclude tension forces.

The initial values of the mechanical characteristics of concrete and infill (uncracked state) were adopted in accordance with the mentioned usual recommendations (Table 1). In the seismic analysis, those values were reduced for the expected cracked state (Table 2).

Table 1. *Table of Materials*

No	Material name	E [kN/m²]	μ	γ [kN/m³]	E_m [kN/m²]	μ_m
1	Brick – medium	3.790e+4	0.2	16.0	2.275e+6	0.2
2	C 25/30	3.100e+7	0.2	25.0	3.100e+7	0.2

Table 2. *Advanced Options of Seismic Analysis*

Masses grouped in the selected ceilings levels	
Beams – reduction of bending stiffness:	0.750
Walls – reduction of bending stiffness:	0.001
Walls – axial stiffness reduction:	0.500
Columns – bending stiffness reduction:	0.750

The gravitational load is identical for all models, so the mass distribution by levels (floors) and the total mass, for all models, is the same (ΣM_{ass}=212 t). The oscillation periods for models Ma, Mb, Mc and Md are 0.532 s, 1.050 s, 0.943 s and 0.943 s, respectively. The behaviour factors were calculated for the *DCM ductility class* in accordance with the structural systems and their regularity. For model Ma, behaviour factor is $q = 0.8 \cdot q_o \cdot k_w = 0.8 \cdot 3 \cdot 1.3 \cdot 1.0 = 3.12$, and for remaining models (Mb, Mc and Md) behaviour factor is $q = q_o \cdot k_w = 3 \cdot 1.3 \cdot 1.0 = 3.90$. The distribution of seismic forces by levels (floors) and the total seismic force ΣS, differ for each model. Thus, for models Ma, Mb, Mc and Md, the values for ΣS are 399 kN, 190 kN, 180 kN and 180 kN, respectively.

Project spectra are given for models Ma and Mb (Figure 12). Models Mc and Md show small deviations from model Mb, so a separate presentation is omitted.

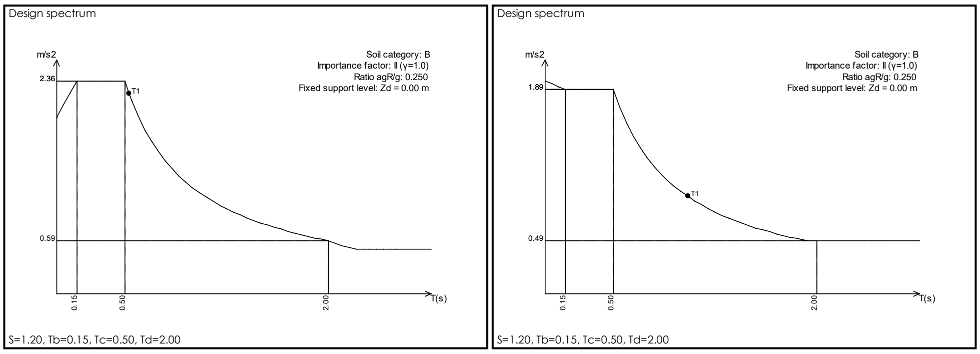

Figure 12. Design spectra: a) for model Ma (T_1=0.532 s, ΣS=399 kN); b) for model Mb (T_1=1.050 s, S=190 kN). Diagrams by authors (Radimpex Tower 8).

For display of characteristic calculation results, diagrams of horizontal displacements X_d and columns bending moments M_3, induced by the horizontal seismic force, are presented (Figures 13-16).

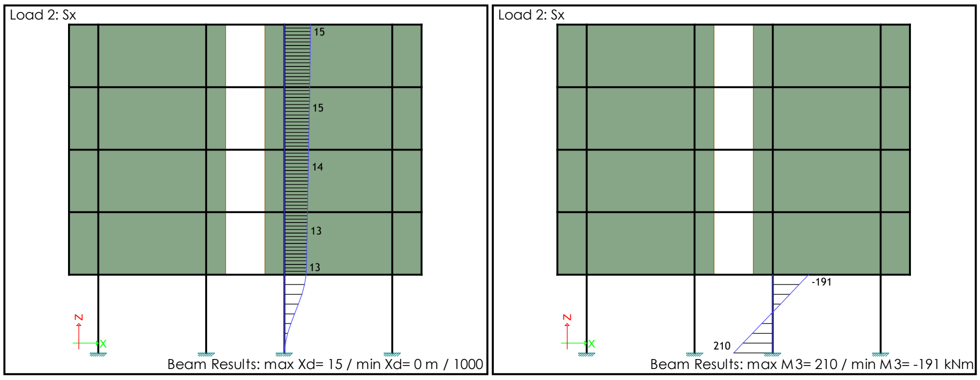

Figure 13. Model Ma impacts: a) horizontal displacement; b) column bending moments. Diagrams by authors, (Radimpex Tower 8).

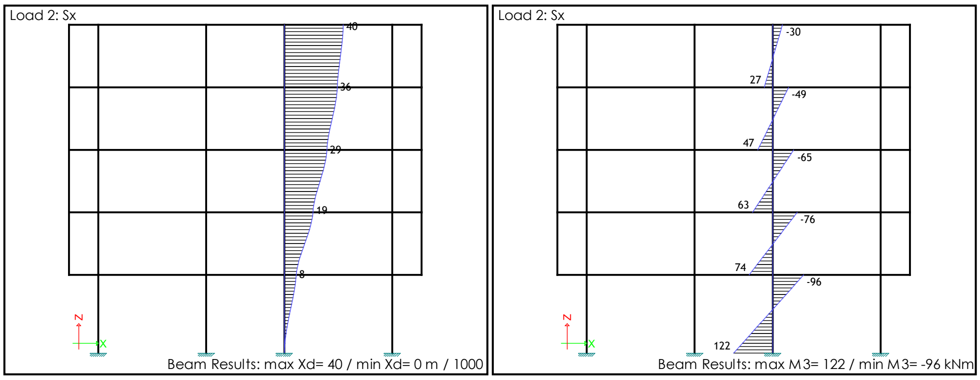

Figure 14. Model Mb impacts: a) horizontal displacement; b) column bending moments. Diagrams by authors, (Radimpex Tower 8).

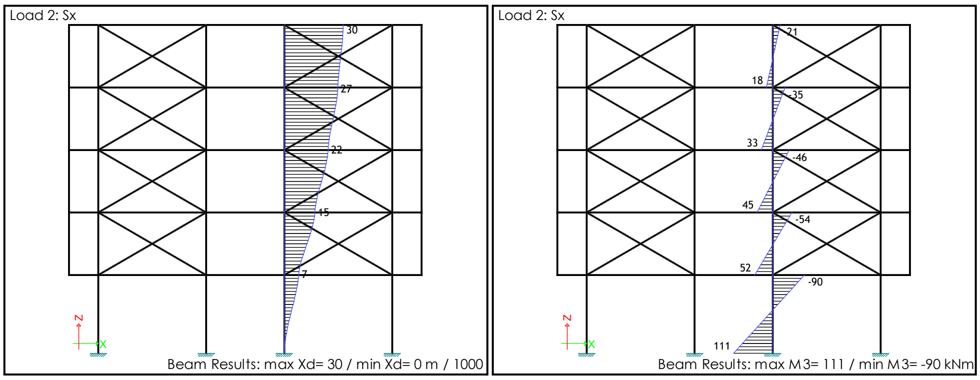

Figure 15. Model Mc impacts: a) horizontal displacement; b) column bending moments. Diagrams by authors, (Radimpex Tower 8).

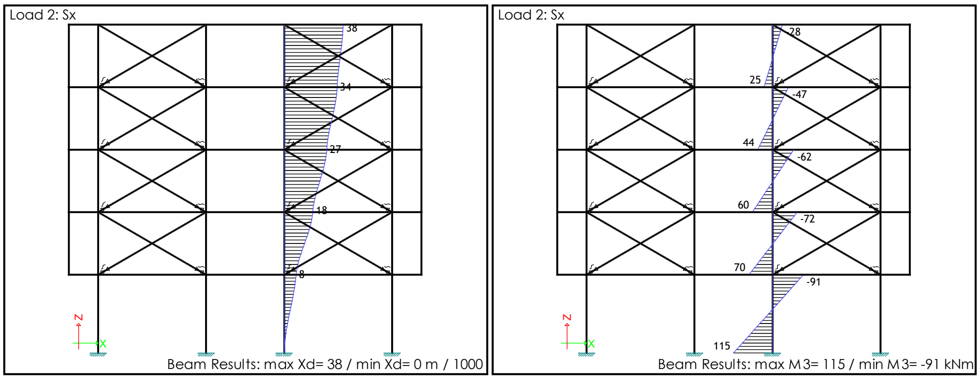

Figure 16. Model Md impacts: a) horizontal displacement; b) column bending moments. Diagrams by authors, (Radimpex Tower 8).

2.2. DISCUSSION OF ANALYSIS RESULTS

From the comparison of the results for the frame without infill and the frame with bonded (non-insulated) infill, a significant drop in the basic oscillation period (by almost 2 times) can be observed, from T=1.050 s for the frame without infill to T=0.532 s for the frame with traditionally bonded infill. On the other hand, the reduction of the period in the case of the frame with equivalent diagonals, compared to the frame without infill is much smaller. The frame with equivalent diagonals has a basic period T=0.943 s, which represents a reduction of only 9%, compared to the frame without infill.

When the oscillation periods on the response spectrum curve are observed (Figure 12), a clear difference can be seen between the frame with bonded infill (model Ma) and the frame without infill (model Mb), showing a significant underestimation of the seismic load level if the infill is not taken into consideration during the calculation. The frame with bonded infill (model Ma) activates a total horizontal force of S=399 kN, whereas the frame without infill activates a force of S=190 kN (model Mb), which is an increase of more than two times. In the frame with bonded infill, the bending moment in the ground floor column is M=210 kNm (model Ma, Figure 13b), while in the frame without infill, that moment is M=122 kNm (model Mb, Figure 14b), which is an increase of approximately 1.7 times. A frame with bonded infill requires a significant increase in reinforcement in the ground floor columns compared to the other frames.

The relative horizontal displacement of the infilled frame floors indicates very small differences, where the absolute floor displacements do not differ a lot from the ground floor displacement (model Ma). This indicates the emergence of a soft ground floor because the horizontal movement of the frame mostly takes place on the ground floor (model Ma, Figure 13a). It is known that the effect of the soft ground floor, due to irregularity, requires the introduction of a smaller behaviour factor, which additionally increases the calculated seismic forces. As expected, due to the increase in stiffness caused by the masonry infill, the displacement of the floors of the frame with bonded infill is significantly less than in the case of the other frames. The maximum horizontal displacement of the frame with bonded infill is X_d=15 mm, while the displacement for isolated infill is X_d=40 mm, which is a decrease of 2.7 times. Also, in the case of frames with bonded infill, the absolute displacements on the ground floor are the largest (X_d=13 mm), compared to all other models (X_d=7.5 mm).

The horizontal floor movement of the frame without infill, due to the uniform stiffness of the floors, indicates its almost linear increase along the height of the building (model Mb,

Figure 14a). As expected, the movement of the floors of the frame without infill indicates that there is no occurrence of a soft ground floor. Also, for the frame without infill, the absolute displacement at the top of the building is greater than the displacement for all other models. The frame with equivalent diagonals is somewhat stiffer than the frame without infill, and the displacements are somewhat smaller (model Mc, Figure 15a). With this frame, the maximum absolute movement at the top of the object is 30 mm, while with the frame without infill, this movement is 40 mm, which is a reduction of 25%. The frame with diagonals, which has a limited ability to receive compressive stress (model Md, Figure 16a), has larger displacements than the frame with standard elastic diagonals, which is expected. The maximum displacement of the frame with the plasticization of the diagonals is 38 mm, which is close to the value of the frame without infill, which is 40 mm.

3. CONCLUSIONS AND RECOMMENDATIONS

In this paper, various instances of masonry infill within calculation models are analysed in accordance with the realistic design and execution of RC frame buildings in Banja Luka and the wider region. Such types of buildings usually have an open ground floor, for business purposes, and floors filled with masonry walls, for residential purposes. The research was conducted to examine the influence of different masonry infill models on the seismic response of an RC frame with an open ground floor. Appropriate conclusions and recommendations were formulated.

The research was conducted on four different models (Ma, Mb, Mc and Md). The basic model consists of a frame without infill (isolated infill) – Mb, and all other models in different ways include masonry infill (continuously bonded, so-called traditional infill – Ma, infill in the form of equivalent elastic diagonals that bear only pressure – Mc and infill in in the form of equivalent diagonals with non-linear behaviour that bear only pressure up to a certain limit – Md). The behaviours between the models were compared, the most interesting being the comparison of the frame with isolated infill (Ma) with the other frames.

The results show that the bonded (non-isolated) infill significantly reduces the natural periods of the frame, thereby increasing the level of seismic load acting on the structure. In addition, the bonded infill produces a soft ground floor effect, which reduces the behaviour factor and increases the intensity of seismic forces. This is not the case with a frame with no infill, or even with a frame filled with equivalent diagonals. The force-displacement curves confirm the low deformation capacity of the frame with traditional infill compared to the frame without an infill and the frames with diagonals. The negative effects of traditional infill on the behaviour of the frame are best illustrated by the large jump in the relative inter-floor displacement, which occurs on the ground floor. In contrast, RC frames with equivalent diagonals behave similarly to unfilled frames, having slightly lower relative inter-story displacements and a gradual increase in absolute displacements along the height of the frame.

Seismic analysis showed very bad effects of traditional infill on the overall behaviour of the building with an open ground floor. The rigid connection of the infill with the frame leads to a significant change in the stiffness of the entire building, which results in a reduction in displacements and the appearance of a soft ground floor (in the case of a building with an open ground floor) and the appearance of significant torsion (in the case of a corner building open to the street). The results show that the building with traditional infill has significantly smaller absolute displacements as well as relative inter-floor displacements, compared to other configurations. However, the movement along the height of the building confirms the occurrence of a soft ground floor that happens due to large movements at the ground floor level, although the relative inter-floor displacements are small. These negative effects can be removed by applying infill insulation, which results in a slight change in displacement and relative inter-floor displacement. The occurrence of a soft ground floor with a frame without infill is not present because the insulation of the masonry infill eliminates the change in stiffness between floors, which comes from the infill. This is confirmed by calculation analyses of the frame without infill and frames with diagonals, that is, the model of the frame without infill can realistically represent the situation of a building with isolated infill.

Based on the presented results, it can be concluded that the traditional infill, continuously attached to the frame columns, significantly changes the behaviour of RC buildings, which is necessary to take into account during the design process. However, modelling masonry infill is a rather complex and difficult task for everyday practice, especially when that numerical model needs to consider the interaction of out-of-plane and in-plane wall influences, which is necessary. In that case, the calculation of RC frame structure with traditional infill is practically impossible. Therefore, the concept of the design of RC buildings with masonry infill must be improved so as to offer engineers a reliable and stable solution based on constructive measures and not on detailed numerical models. The benefit of the isolation procedure is reflected in the delayed activation of the masonry infill and thus the significant increase in deformation capacity, as well as the removal of in-plane and out-of-plane influence interaction, which significantly improves the behaviour of the RC building with infill. The additional contribution of infill insulation is seen in case of any change in the basic structure or infill during the building construction or use because such changes do not have a significant effect on the basic RC frame. In addition, the numerical model in the form of an RC frame, which takes into account the isolated masonry infill only as a load, is simple to use in everyday practice.

The insulation of the masonry infill should be done correctly because its unprofessional separation of from the RC frame can lead to the infill falling perpendicularly to the wall plane. This is especially dangerous for the upper floors of tall buildings because the movements of those floors are significant. Recently, it has been noticeable that in domestic practice this is not taken into account, i.e. there is infill with classic masonry without special insulation, but also without additional connections to the frame in the form of cerclage or anchors. This is the worst possible form because during an earthquake the frames are not saved from the impact of the rigid infill, and the walls are not secured from falling out of the frame. It is necessary to urgently innovate construction rules and procedurally oblige contractors to comply with those rules. This would prevent the possibility of excessive damage to the RC frame and/or walls falling out, thereby endangering human lives and buildings as a result of the earthquake.

4. REFERENCES

[1] G. Broćeta, A. Cumbo, S. Cvijić Amulić, M. Latinović Krndija, E. Zlatanović, S. Šupić, “Seismic waves analysis,” *Book of Proceedings, International Scientific Forum – Geotechnical Aspects of Civil Engineering and Earthquake Engineering*, Vrnjačka Banja, Serbia, pp. 289-298, 2023.

[2] A. Cumbo, “Evaluation of seismic resistance of existing buildings – experience from Banja Luka,” *Conference proceedings, Ninth international conference: Assessment, maintenance and rehabilitation of structures and settlements*, Zlatibor, Serbia, pp. 569-578, 2015. (in Serbian).

[3] A. Cumbo, “The reinforcement and upgrading of existing buildings complex in Sarajevo,” *Conference proceedings, Sixth international conference: Earthquake engineering and engineering seismology*, Kraljevo, Serbia, pp. 457-464, 2018. (in Serbian).

[4] A. Cumbo, “Structure state assessment of the public health institute building in Banja Luka,” *Conference proceedings, Eleveenth international conference: Assessment, maintenance and rehabilitation of structures and settlements*, Zlatibor, Serbia, pp. 271-282, 2019. (in Serbian).

[5] J. Radnić, N. Grgić, A. Buzov, I. Banović, M. Smilović Zulim, G. Baloević, M. Sunara, “Mw 6.4 Petrinja earthquake in Croatia: Main earthquake parameters, impact on buildings and recommendation for their structural strengthening,” *Građevinar,* vol. 73, no. 11, pp. 1109-1128, 2021, doi: 10.14256/JCE.3243.2021.

[6] M. Šavor Novak, M. Uroš, J. Atalić, M. Herak, M. Demšić, M. Baniček, D. Lazarević, N. Bijelić, M. Crnogorac, M. Todorić, “Zagreb earthquake of 22 March 2020 – preliminary report on seismologic aspects and damage to buildings,” *Građevinar*, vol. 72, no. 10, pp. 843-867, 2020, doi: 10.14256/JCE.2966.2020.

[7] H.C. Mertol, G. Tunc, T. Akis, “A site survey of damaged RC buildings in İzmir after the Aegean sea earthquake on October 30,” *Građevinar,* vol. 75, no. 5, pp. 451-470, 2023, doi: 10.14256/JCE.3343.2021.

[8] A. Arbinja. D. Janković, R. Vukomanović G. Broćeta, A. Cumbo, “Razorni zemljotresi u Turskoj i Siriji – uzroci i posljedice,” *SAG+, Sav. grad. – Časopis za arh., građ. i geod.*, vol. 13, pp. 20-27, 2023. (in Serbian).

[9] F. Braga, V. Manfredi, A. Masi, A. Salvatori, M. Vona, “Performance of non-structural elements in RC buildings during the L’Aquila, 2009 earthquake,” *Bull. of Earth. Eng.*, vol. 9, no. 1, pp. 307-324, 2011, doi: 10.1007/s10518-010-9205-7.

[10] L. Hermanns, A. Fraile, E. Alarcón, R. Álvarez, “Performance of buildings with masonry infill walls during the 2011 Lorca earthquake,” *Bull. of Earth. Eng.*, vol. 12, no. 5, pp. 1977-1997, 2014, doi: 10.1007/s10518-013-9499-3.

[11] A. Masi, L. Chiauzzi, G. Santarsiero, V. Manfredi, S. Biondi, E. Spacone, C. Del Gaudio, P. Ricci, G. Manfredi, G.M. Verderame, “Seismic response of RC buildings during the M w 6.0 August 24, 2016 Central Italy earthquake, The Amatrice case study,” *Bull. of Earth. Eng.*, vol. 17, no. 10, pp. 5631-5654, 2017.

[12] S. Nikolić-Brzev, M. Marinković, I. Milicević, N. Blagojević, “Posledice zemljotresa u Albaniji od 26.11.2019. na objekte i infrastrukturu,” (Consequences of the November 26, 2019 Albania earthquake on the buildings and infrastructure), *Serbian Association for earthquake engineering (SUZI-SAEE)*, Belgrade, Serbia, p. 80 p, 2020. (in Serbian).

[13] H. Varum, A. Furtado, H. Rodrigues, J. Dias-Oliveira, N. Vila-Pouca, A. Arêde, “Seismic performance of the infill masonry walls and ambient vibration tests after the Ghorka 2015, Nepal earthquake,” *Bull. of Earth. Eng.*, vol. 15, no. 3, pp. 1185-1212, 2017, doi: 10.1007/s10518-016-9999-z.

[14] S. Yousefianmoghadam, M. Song, M.E. Mohammadi, B. Packard, A. Stavridis, B. Moaveni, R.L. Wood, “Nonlinear dynamic tests of a reinforced concrete frame building at different damage levels,” *Earth. Eng. and Struct. Dyn.*, vol. 49, no. 9, pp. 924-945, 2020, doi: 10.1002/eqe.3271.

[15] P. Ricci, G.M. Verderame, G. Manfredi, “Analytical investigation of elastic period of infilled RC MRF buildings,” *Eng. Struc.*, vol. 33, no. 2, pp. 308-319, 2011, doi: 10.1016/j.engstruct.2010.10.009.

[16] P.G. Asteris, C.C. Repapis, A.K. Tsaris, F. Di Trapani, L. Cavaleri, “Parameters affecting the fundamental period of infilled RC frame structures,” *Earth. and Struct.*, vol. 9, no. 5, pp. 999-1028, 2015, doi: 10.12989/eas.2015.9.5.999.

[17] D. Perrone, E. Brunesi, A. Filiatrault, R. Nascimbene, “Probabilistic estimation of floor response spectra in masonry infilled reinforced concrete building portfolio,” *Eng. Struct.*, vol. 202, 109842, 2020, doi: 10.1016/j.engstruct.2019.109842.

[18] G. Al-Chaar, M. Issa, S. Sweeney, “Behavior of masonry-infilled nonductile reinforced concrete frames,” *Jour. of Struct. Eng.*, vol. 128, no. 8, pp. 1055-1063, 2002, doi: 10.1061/(ASCE)0733-9445(2002)128:8(1055).

[19] A. Stavridis, P.B. Shing, “Finite-element modeling of nonlinear behavior of masonry-infilled RC frames,” *Jour. of Struct. Eng.*, vol. 136, no. 3, pp. 285-296, 2010, doi: 10.1061/(ASCE)ST.1943-541X.116.

[20] C. Zhai, J. Kong, X. Wang, Z. Chen, “Experimental and finite element analytical investigation of seismic behavior of full-scale masonry infilled RC frames,” *Jour. of Earth. Eng.*, vol. 20, no. 7, pp. 1171-1198, 2016, doi: 10.1080/13632469.2016.1138171.

[21] S. Hak, P. Morandi, G. Magenes, “Prediction of inter-storey drifts for regular RC structures with masonry infills based on bare frame modelling,” *Bull. of Earth.Eng.*, vol. 16, pp. 397–425, 2017, doi: 10.1007/s10518-017-0210-y.

[22] A. Furtado, H. Rodrigues, A. Arêde, H. Varum, “Out-of-plane behavior of masonry infilled RC frames based on the experimental tests available: A systematic review,” *Const. and Build. Mat.*, vol. 168, pp. 831-848, 2018, doi: 10.1016/j.conbuildmat.2018.02.129.

[23] A. Furtado, H. Rodrigues, A. Arêde, H. Varum, “Assessment of the mainshock-aftershock collapse vulnerability of RC structures considering the infills in-plane and out-of-plane behaviour,” *Proc. Eng.*, vol. 199, pp. 619-624, 2017, doi: 10.1016/j.proeng.2017.09.107.

[24] M.T. De Risi, M. Di Domenico, P. Ricci, G.M. Verderame, G. Manfredi, “Experimental investigation on the influence of the aspect ratio on the in-plane/out-of-plane interaction for masonry infills in RC frames,” *Eng. Struct.*, vol. 189, pp. 523-540, 2019, doi: 10.1016/j.engstruct.2019.03.111.

[25] C. Butenweg, M. Marinković, R. Salatić, “Experimental results of reinforced concrete frames with masonry infills under combined quasi-static inplane and out-of-plane seismic loading,” *Bull. of Earth. Eng.*, vol. 17, no. 6, pp. 3397-3422, 2019, doi: 10.1007/s10518-019-00602-7.

[26] K. Kostinakis, A. Athanatopoulou, “Effects of in-plan irregularities caused by masonry infills on the seismic behavior of R/C buildings,” *Soil Dyn. and Earth. Eng.*, vol. 129, 2020, doi: 10.1016/j.soildyn.2019.03.012.

[27] M. Ferraioli, A. Lavino, “Irregularity Effects of Masonry Infills on Nonlinear Seismic Behaviour of RC Buildings,” *Math. Prob. in Eng.*, vol. 59, pp. 105737, 2020, doi: 10.1155/2020/4086320.

[28] O. Onat, A.A. Correia, P.B. Lourenço, A. Koçak, “Assessment of the combined in-plane and out-of-plane behavior of brick infill walls within reinforced concrete frames under seismic loading,” *Earth. Eng. and Struct. Dyn.*, vol. 47, no. 14, pp. 2821-2839, 2018, doi: 10.1002/eqe.3111.

[29] T.K. Padhy, A.M. Prasad, D. Menon, D.P. Robin, “Seismic Performance Assessment of Open Ground Storey Buildings,” *Proceedings, 15th World Conference on Earthquake Engineering*, Lisbon, 2012.

[30] A. Pokhrel, D. Gautam, H. Chaulagain, “Effect of variation on infill masonry walls in the seismic performance of soft story RC building,” *Austr. Jour. of Struct. Eng.*, vol. 20, no. 1, pp. 1-9, 2019, doi: 10.1080/13287982.2018.1546449.

[31] Y.J. Chiou, J.C. Tzeng, Y.W. Liou, “Experimental and analytical study of masonry infilled frames,” *Journal of Structural Engineering*, vol. 125, no. 10, pp. 1109-1117, 1999, doi: 10.1061/(ASCE)0733-9445(1999)125:10(1109).

[32] C.V.R. Murty, S. Brzev, H. Faison, A. Irfanoglu, C.D. Comartin, “ At risk: The seismic performance of reinforced concrete frame buildings with masonry infill walls. A tutorial developed by a committee of the World Housing Encyclopedia, a project of the Earthquake Engineering Research Institute and the International Association for Earthquake Engineering,” *Earth. Eng. Res. Inst*., Oakland, California, 2006. Accessed: Jan 12, 2024. [Online]. Available: https://www.world-housing.net/wp-content/uploads/2011/05/RCFrame_Tutorial_English_Murty.pdf

[33] L. Liberatore, F. Mollaioli, “Influence of masonry infill modelling on the seismic response of reinforced concrete frames,” *Civil-Comp Proceedings*, vol. 108, pp. 1-17, 2015.

[34] F.J. Crisafulli, “Seismic behaviour of reinforced concrete structures with masonry infills,” Ph.D. dissertation, Depart. of Civ. Eng., University of Canterbury, Christchurch, New Zealand, 1997.

[35] P.G. Asteris, “Finite element micro-modelling of infilled frames,” *Elect. Jour. of Struct. Engi.*, vol. 8, pp. 1-11, 2008, doi: 10.56748/ejse.894.

[36] R. Žarnić, M. Tomaževič, “An Experimentally Obtained Method for Evaluation of the Behaviour of Masonry Infilled R/C Frames,” *Proceedings of the 9th World Conference on Earthquake Engineering*, Tokyo, Japan, Vol. VI, pp. 163-168, 1988.

[37] B.S. Smith, “Lateral stiffness of infilled frames,” *Jour. of the Struct. Div.*, vol. 88, no. 6, pp. 183-226, 1962.

[38] G. Al-Chaar, “Evaluating strength and stiffness of unreinforced masonry infill structures (No. ERDC/CERL-TR-02-1),” *Engineer research and development center champaignil construction engineering research lab*, 2002.

[39] C.Z. Chrysostomou, P.G. Asteris, “On the in-plane properties and capacities of infilled frames,” *Eng. Struct.*, vol. 41, pp. 385-402, 2012, doi: 10.1016/j.engstruct.2012.03.057.

[40] B. Stafford-Smith, H. Coull, “Infilled-Frame Structures,” *Tall Building Structures: Analysis and Design, John Wiley and Sons*, Inc., New York, pp. 168-183, 1991.

[41] T.B. Panagiotakos, M.N. Fardis, “Seismic response of infilledrc frames structures”. *11th World Conference on Earthquake Engineering*, paper 225, pp. 23-28, 1996.

[42] M. Dolšek, P. Fajfar, “The effect of masonry infills on the seismic response of a fourstorey reinforced concrete frame – a deterministic assessment,” *Eng. Struct.*, vol. 30, no. 7, pp. 1991–2001, 2008, doi: 10.1016/j.engstruct.2008.01.001.

[43] P.B. Shing, A. Stavridis, “Analysis of seismic response of masonry-infilled RC frames through collapse,” *ACI Symposium Publication, vol. 297.*, pp. 1–20, 2014.

[44] R.E. Klingner, V.V. Bertero, “Infilled frames in earthquake resistant construction,” Report No. EERC 76-32, University of California, Berkely, 1976.

[45] F.J. Crisafulli, A.J. Carr, “Proposed macro-model for the analysis of infilled frame structures,” *Bull. NZ Soc. Earth. Eng*, vol. 40, no. 2, pp. 69–77, 2007, doi: 10.5459/bnzsee.40.2.69-77.

[46] L. Cavaleri, M. Fossetti, M. Papia, “Infilled frames: developments in the evaluation of cyclic behaviour under lateral loads,” *Struct. Eng. and Mech.*, vol. 21, no. 4, pp. 469-494, 2005, doi: 10.12989/sem.2005.21.4.469.

[47] G.M. Calvi, D. Bolognini, “Seismic response of reinforced concrete frames infilled with weakly reinforced masonry panels,” *Jour. of Earth. Eng.*, vol. 5, no. 2, pp. 153-185, 2001, doi: 10.1080/13632460109350390.

[48] A. Furtado, H. Rodrigues, A. Arêde, H. Varum, “Experimental tests on strengthening strategies for masonry infill walls: A literature review,” *Const. and Build. Mat.*, vol. 263, pp. 120520, 2020, doi: 10.1016/j.conbuildmat.2020.120520.

[49] F. Da Porto, G. Guidi, N. Verlato, C. Modena, “Effectiveness of plasters and textile reinforced mortars for strengthening clay masonry infill walls subjected to

combined in-plane/out-ofplane actions/Wirksamkeit von Putz und textilbewehrtem Mörtel bei der Verstärkung von Ausfachungswänden aus Ziegelmauerwerk, die kombinierter Scheiben-und Plattenbeanspruchung ausgesetzt sind," *Mauerwerk*, vol. 19, no. 5, pp. 334-354, 2015, doi: 10.1002/dama.201500673.

[50] F. Akhoundi, G. Vasconcelos, P. Lourenço, L.M. Silva, F. Cunha, R. Fangueiro, "In-plane behavior of cavity masonry infills and strengthening with textile reinforced mortar," *Eng. Struct.*, vol. 156, pp. 145-160, 2018, doi: 10.1016/j.engstruct.2017.11.002.

[51] D.A. Pohoryles, D.A. Bournas, "Seismic retrofit of infilled RC frames with textile reinforced mortars: State-of-the-art review and analytical modelling," *Compos. Part B: Eng.*, vol. 183, pp. 107702, 2020, doi: 10.1016/j.compositesb.2019.107702.

[52] M. Preti, N. Bettini, G. Plizzari, "Infill walls with sliding joints to limit infill-frame seismic interaction: large-scale experimental test," *Jour. of Earth. Eng.*, vol. 16, no. 1, pp. 125-141, 2012, doi: 10.1080/13632469.2011.579815.

[53] M. Preti, L. Migliorati, E. Giuriani, "Experimental testing of engineered masonry infill walls for post-earthquake structural damage control," *Bull. of Earth. Eng.*, vol. 13, no. 7, pp. 2029-2049, 2015, doi: 10.1007/s10518-014-9701-2.

[54] N. Verlato, G. Guidi, F. Da Porto, C. Modena, "Innovative systems for masonry infill walls based on the use of deformable joints: combined inplane/out-of-plane tests," in *Brick and Block Masonry*, CRC Press, 2016, pp. 1359-1366.

[55] P. Morandi, R.R. Milanesi, G. Magenes, "Innovative solution for seismic-resistant masonry infills with sliding joints: in-plane experimental performance," *Eng. Struct.*, vol. 176, pp. 719-733, 2018, doi: 10.1016/j.engstruct.2018.09.018.

[56] Q. Peng, X. Zhou, C. Yang, "Influence of connection and constructional details on masonryinfilled RC frames under cyclic loading," *Soil Dyn. and Earth. Eng.*, vol. 108, pp. 96-110, 2018, doi: 10.1016/j.soildyn.2018.02.009.

[57] A.V. Tsantilis, T.C. Triantafillou, "Innovative seismic isolation of masonry infills using cellular materials at the interface with the surrounding RC frames," *Eng. Struct.*, vol. 155, pp. 279-297, 2018, doi: 10.1016/j.engstruct.2017.11.025.

[58] J.S. Kuang, Z. Wang, "Cyclic load tests of rc frame with column-isolated masonry infills," In *Second European Conference on Earthquake Engineering and Seismology*, Istanbul, pp. 25-29, 2014.

[59] L. Facconi, F. Minelli, "Retrofitting RC infills by a glass fiber mesh reinforced overlay and steel dowels: experimental and numerical study," *Const. and Build. Mat.*, vol. 231, 117133, 2020, doi: 10.1016/j.conbuildmat.2019.117133.

[60] M. Marinković, C. Butenweg, "Innovative decoupling system for the seismic protection of masonry infill walls in reinforced concrete frames," *Eng. Struct.*, vol. 197, 109435, 2019, doi: 10.1016/j.engstruct.2019.109435.

[61] M. Marinković, S. Flores Calvinisti, C. Butenweg, "Numerical analysis of reinforced concrete frame buildings with, decoupled infill walls," *Build. Mat. and Struct.,* vol. 63, no. 4, pp. 13-48, 2020, doi: 10.5937/GRMK2004013M.

[62] FEMA 356, "Prestandard and Commentary for the Seismic Rehabilitation of Buildings," *Fed. Emerg. Manag. Ag.*, Washington, D.C., U.S.A., 2000.

[63] N. M. Noh, L. Liberatore, F. Mollaioli, S.Tesfamariam, "Modelling of masonry infilled RC frames subjected to cyclic loads: State of the art review and modelling with OpenSees," *Eng. Struct.*, vol. 150, pp. 599-621, 2017, doi: 10.1016/j.engstruct.2017.07.002.

[64] L. Liberatore, F. Noto, F. Mollaioli, P. Franchin, "In-plane response of masonry infill walls: Comprehensive experimentally-based equivalent strut model for deterministic and probabilistic analysis," *Eng. Struct.*, vol. 167, pp. 533-548, 2018, doi: 10.1016/j.engstruct.2018.04.057.

[65] M. M. Abdelaziz, M. S. Gomaa, H. El- Ghazaly, “Seismic evaluation of reinforced concrete structures infilled with masonry infill walls,” *A. Jour. of Civ. Eng.*, vol. 20, pp. 961–981, 2019, doi: 10.1007/s42107-019-00158-6.

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УТИЦАЈ ИЗБОРА ТИПА МОДЕЛА ЗИДАНЕ ИСПУНЕ НА СЕИЗМИЧКИ ОДГОВОР АРМИРАНОБЕТОНСКИХ ОКВИРНИХ ЗГРАДА

Сажетак: Армиранобетонски (АБ) оквири су, у многим земљама, широко заступљени као главна конструкција зграда. При томе се испуна оквира најчешће изводи традиционалним зидањем (опекарски елементи повезани малтером) без раздвајања од оквира. Познато је да се у инжењерској пракси прорачунске анализе АБ оквирних зграда на сеизмичке силе уобичајено раде на моделима без укључивања зидане испуне, чак и у случајевима када посебним конструктивним мјерама испуна није изолована од оквира, при чему се зидови узимају само као стално оптерећење. Тиме је потпуно занемарен допринос неизоловане зидане испуне на промјену носивости, крутости и дуктилности АБ оквира, односно на промјену напрезања и хоризонталног помјерања конструкције приликом дејства сеизмичких сила. У циљу сагледавања посљедица овако, за праксу уобичајено, постављеног прорачунског модела, у раду су анализирана четири карактеристична типа модела АБ оквира са зиданом испуном. Показало се да различито постављени модели исте зграде мијењају динамичке карактеристике, односно силе и помјерања главне оквирне конструкције. Наиме, приказаном динамичком анализом, показује се да због неадекватног третирања везе оквира и неизоловане испуне, у фази пројектовања, на жалост, неријетко, “остају непримјећене” врло опасне појаве попут “меке етаже”, значајне торзије и сл. Стога се у раду наглашава важност да се у свакодневној инжењерској пракси неизолована испуна третира у прорачунском моделу на едекватан начин. Такође, у раду се апелује на потребу да се донесу прецизна упутства за посебне конструктивне мјере, којим би се потпуно изоловала зидана испуна од оквира, када је такво рјешење оправдано.

Кључне ријечи: АБ оквирне зграде, зидана испуна, динамичке карактеристике, крутост и дуктилност испуне