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Create a Rigid and Safe Grid-like Structure

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Abstract

The failure of the building is not the consequence of the not strong enough elements of the structure in the majority of the cases, but the bracing elements inappropriate places. We consider a 4 × 4 and 4 × 5 braced frames to understand the connections between the lateral stiffnesses, and bracing graph to achieve the stiffest and the more safety design. In our consideration, we study those relationships that based on our frame using their finite element analyses and some new result in optimizations of structural design. We offer some conclusions, including perspectives and future developments in the rigidity of scaffolds and tall building as symmetrical and grid-like bar-joint frameworks.

Keywords

braced scaffolding, n-story building, the safety of the structure, kinematics of braced structure

1 Introduction

In this study, we investigate the scaffolding assembled on construction; to use discrete optimization, we try to predict the rigidity or the stiffness of the ideal square grid framework and to determine the maximal displacement of the structure.

The goal is to establish not the measures but the structure of the framework to prevent accidents as the collapse of improperly structured bar-joint scaffolding and in a tall building.

We offer some conclusions, including perspectives and future developments in the rigidity of scaffolds and tall building as bar-joint frameworks.

Failures of the scaffoldings, stand structures, and tall building led to the versions of national standards [1–7]. The Scaffolding structures made from prefabricated components such as modular scaffolds, and scaffolds made from steel tubes fitting some joint-type object [8–11] or bamboo [12]. Comparing the European practice, we found that tube-and-fitting scaffolds used a variety of different system.

This paper shows that braced scaffold structures fail primarily by not adequate structural design instead of elastic instability. Some of the designers put the bracing elements inappropriate places. Harung et al. [13] constructed model single story tower scaffolds, which were loaded by dead loads on the top. A stability-function [14, 15] based finite element program to analyze the structures. However, in the models, all joints were either pinned or fixed, and no eccentricity of either member or connection was included – the later research show new result of the stiffness for some scaffolds [16].

The deflection analysis of multi-story frameworks uses the analysis of the scaffolding if they consider only the shear loading of the structure, i.e., this consideration neglect the lateral movements that are combined with rotation.

The mathematical problem of parallel beams interconnected by cross bars in tall buildings frameworks was presented in [17]. The method was applied to wind load. The author disregards the effect of the axial deformation of the columns or beams or both of them. Similarly, the theoretic result of Maxwell [18] for the frameworks that consist of ideal bars and joints presents a necessary and sufficient assumption for the rigidity of the arbitrary framework. For periodical structures in the 3-dimensional space was given a better characterization by Bolker and Crapo's one story building and in the case n-story building of Radics, and the annex building of Nagy [19–32]. Numerous methods were published for the stability of periodic frameworks as bracing, shear walls, cores, or actuators [5, 33–43].

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Zalka presented practical results in [44–46] and nearly in [47–49], which can determine the maximum deflection of multi-story buildings. These results used the continuum method and gave a useful general practical application.

Some other considerations as discrete methods as simulation and FEM provide the characterization of the stability for the given but could be general enough configuration.

The aim of our paper is:

- To revisit the accuracy of the procedures based on the results of the test cases 4 × 4 structure in papers [16].
- To present the usefulness of the discrete method for the lateral stiffness of the two and three-dimensional braced grid-type structure.

2 The Braced 4 × 4 Frameworks

The wind and earthquakes loads of buildings are the main challenges for structural engineers to increase the height of the building keeping the displacements under control and cover expenses. The tallest buildings consist of the well-designed structural system, that we can use modeling by bar-joint systems that easy to produce and to build, although the manufacturer and the assembly workers go against this statement. Innovative design, building methods, combined with the reinforced materials as high-strength concrete widely used in high-rise buildings and scaffolding [1, 3, 13–15, 50–60].

2.1 The properties of the elements of the structure

The structures are regular, i.e., the properties of the elements of the structure do not change the height, and the horizontal beams and the vertical column can rotate freely around the connected joints in case that will be considered by FEM. In this case, the deformations are small, and the material of the structures is linearly elastic.

In the braced bar-joint framework, the bracing arrangements will decrease the lateral displacement and raise the stability. Perhaps, the Steel bracing has the stiffest construction in resisting lateral loads. The Reinforced Concrete frameworks also a good candidate to resist the statical and the dynamical lateral loads. Many results showed that the braced frame with strong enough elastic bracing elements resisted higher lateral loads than the moment frames see the left picture of Fig. 1, the bracing element and provided the stability of the all building. On the right, a "reinforced" concrete framework with shear walls that could regard as good practice in design, since the consequence of the high loads of the collapsing the structure remained intact most places, but it was catastrophic in the practice of the quality management [61]. Designing the 2-dimensional braced frames for an acceptable seismic and wind load is the first step in the development of designing high buildings.

Fig. 1 On the pictures, we can see the frameworks of the demolished buildings without diagonal braces. In the top picture, a wooden framework, that lost their walls as braced elements at the 1995 Kobe earthquake (photo by Michio Miyano) [62]. In the picture below we can see the side view of the building that lays on its front side at 2016 earthquake Tainan, southern Taiwan (captured picture from [63]). We can see both of the cases the shear deformation of the structure

2.2 The two-dimensional case

For the lateral stiffness of bar-joint square grid framework, we use diagonal bracing elements. In this paper, we consider the effective arrangement of brace members for stabilizing the structure and making stiffer frameworks.

The optimal arrangement of bracing elements in a framework is a multidisciplinary problem that has been studied using distinct approaches. One is based on statics concepts, the second is the computer-based optimization, and the third one is the approach of combinatorial optimization. The basic concept of the first two methods considers the physical and geometrical (sizes) properties of the structures. Generally, the topology of the structure is given. The optimization provides the sizes and the materials of the

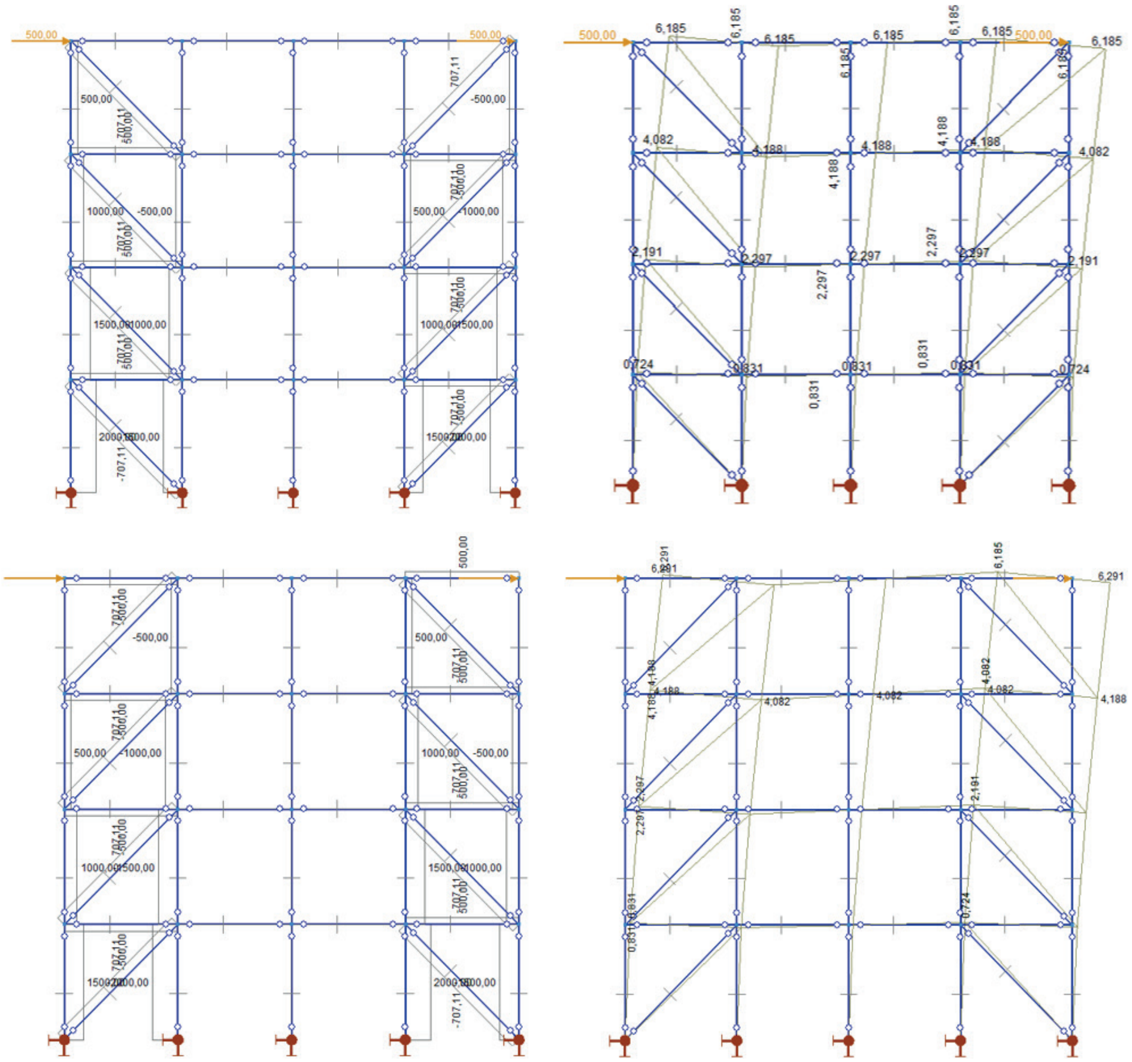


Fig. 2 On the left up and down, we can see the two frameworks with the two greatest displacements, with the normal forces (perpendicular to the cross-section) of the elements. On the rights, the displacements are visualized of the stories

member, using loads in a defined bracing system. It does not significantly improve structural efficiency disregarding the topology optimization. The results of combinatorial optimization for bar joints structures give useful input to find the optimal bracing patterns. The well-known brace configurations are shown X, V, K mega bracing patterns.

The [8, 16] consider a 4 × 4 braced frame to understand the connections between the lateral stiffnesses, and bracing patterns to achieve the stiffest design. In our consideration, we study those relationships that based on a four-bay and four-story braced frame using their analyses. Similarly, we placed two bracing elements arbitrarily in each of the stories. The authors put the two diagonal braces into four locations (flats) in each of the stories. Hence the number of cases is

$$\binom{4}{2} = 6 . \tag{1}$$

There are two directions of the diagonals; hence, the number of cases are multiplied by four. Hence, the number of all cases is 24^4 possible arrangements in their consideration, and our there would be the number of the possible arrangements $24^5 = 7962624$ in our review.

In this study, we also consider the steel pipe assembled scaffolding, in the plane, we reconsider the four-story building framework to test how they response lateral loads by finite element analyses.

Comparing the responses of the frameworks in the regards of the earlier consideration of the calculated displacement in [16], using the Axis VM 13 structural analysis with the linear method in our consideration, there was almost full accordance with five digits.

On Fig. 2, we can see our FEM model of the 4 × 4 building. The diagonal braces are under tension and compression loads. On the right, we can see the deformation of

Fig. 3 We can see the three scaffolding frameworks with the largest displacements that possible in the lateral direction if we use the same number or diagonal braces

the elements, and the maximal displacement readable on the upper right corner of the building. On the left-hand side of the FEM, figures show the forces of the bars – is compression, + is the tension in Newton. The right-hand side picture of the FEM figures shows the horizontal displacement of the endpoint of the last slab elements of the floor in mm-s. The movement of the framework is visualized in the right picture with an affinity map to the displacements of the original framework. The bars connect by joints and to the ground also. The bending rigidity of the bars is the same, the geometry also the in the case of columns and beams, steel S235, and the loads are 500–500N in the right horizontal direction in the upper corner point in central force manner. Hence, the exact measure of the date is insufficient. The calculated displacements can change the ratio of the loads, in the case of elastic deformation, i.e., neglect the overstrain of the framework.

We can see the frameworks which present the largest displacements in Fig. 2. Hence they are the less stiff configuration of the scaffolding. However, they have used in the architectural industry, see the pictures of Fig. 3. The

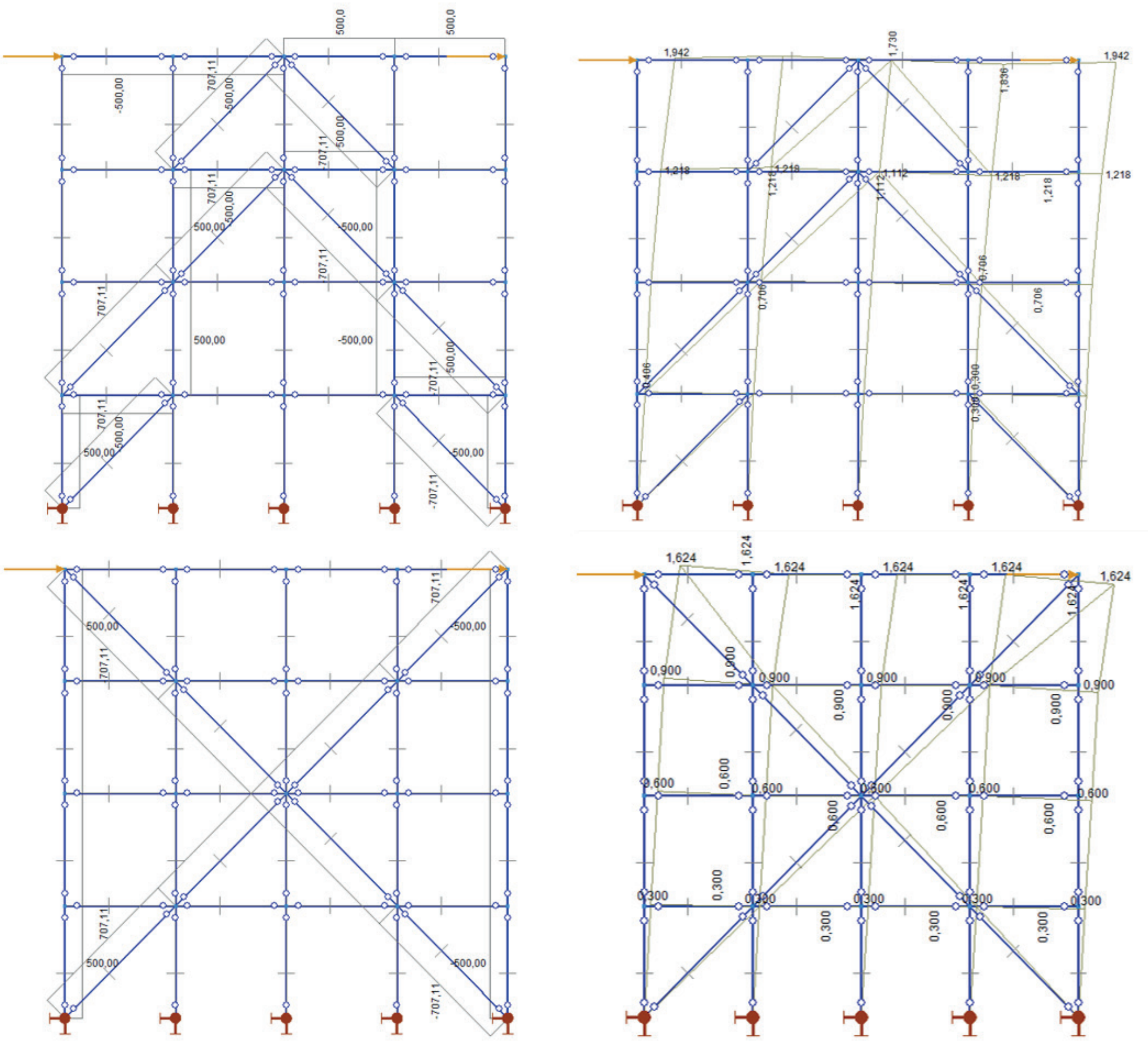
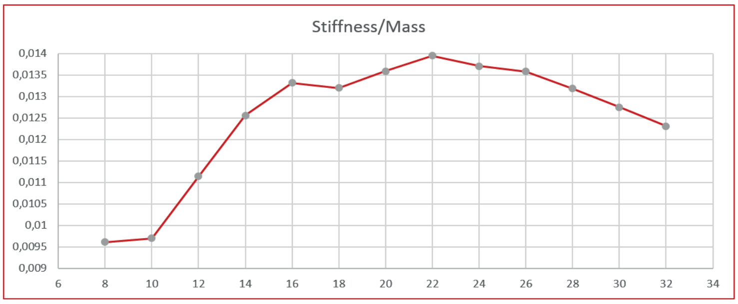


Fig. 4 On the left up and down, we can see the two frameworks with the fewest displacements, with the normal forces of the elements. On the right, we can see the displacements of the stories



#B	8	10	12	14	16	18	20	22	24	26	28	30	32
d	2,199	2,056	1,695	1,427	1,281	1,233	1,145	1,068	1,043	1,012	1,003	1,0	1,0
M	47,3	50,1	53,0	55,8	58,6	61,5	64,3	67,1	69,9	72,8	75,6	78,4	81,3
dM	104,0	103,1	89,8	79,6	75,1	75,8	73,6	71,7	72,9	73,6	75,8	78,4	81,3
1/dM	0,0096	0,0097	0,0111	0,0126	0,0133	0,0132	0,0136	0,0140	0,0137	0,0136	0,0132	0,0128	0,0123

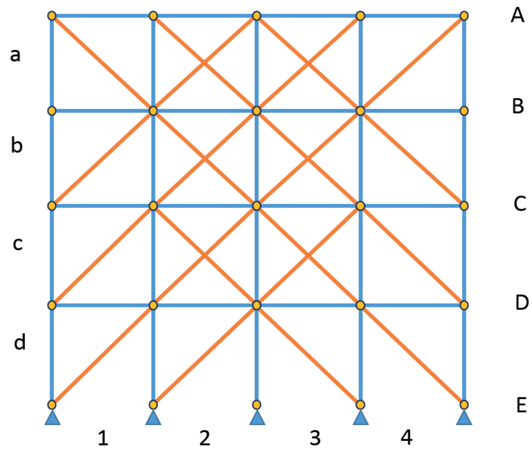


Fig. 5 On the left up, we can see the graph that shows that in the case of 22 pieces of diagonal will be the smallest displacement to unit mass of the optimal 4 × 4 framework. On the right, we can see the corresponding braced framework

diagonals are in the same columns above each other, and our calculation showed that these are one of the less rigid configurations. However, they are stiffer than we do not use any diagonals as the building on Fig. 1.

The frameworks, which present the smallest displacements show a mega-diagonal pattern. We verify that the mega X brace is the stiffest brace pattern.

It is evident that if we use more diagonals than the minimum movement of the all possible pattern will be smaller. Hence we get a stiffer structure. On the right of Fig. 5, we can see the maximal stiffness of framework, which are braced not less than eight symmetrical diagonals. On the right picture, we can see the greatest stiffness in the ratio of the mass M of the used elements (8–32 diagonals, 16 beams and 20 column that are increased by their length). Bottom of the left we can see the table, that first two row adapted from [16]. M is the sum of the length of the used elements in the braced structure, which proportionate the mass of the scaffolding where #B means the number of the used diagonal braces.

Confront this right-hand side pattern of Fig. 5 with the upper framework of Fig. 4 we ask the next questions:

1. Why are there fewer diagonals on the first floor than the uppers?
2. Why are these patterns different from the pattern of the optimal cantilever that is considered in for example in [64, 65]?

Another important question is raised:

3. Can we find a good characterization that describes the deflection of an n-story two-dimensional building in the function of the bracing patterns, and one or more lateral loading force?

3 The Braced 5 × 4 Frameworks

Some of the standards or their guide, for example, the OSHA Guide [4, 66] show the tube assembled scaffolding on Fig. 6 with two long-braces on the inner side and the outer side of the 5 × 4 frameworks scaffolding.

3.1 A false practice and a corrected mistake

In the guide of the OSHA standard, the long tubes are fixed to the left columns down and fixed to the right columns up. If the left-handed side columns are not fixed to the ground, then the force F_1 could lift the first column, (some other mistakes in these and other standards are mentioned in [6]). The signed connection of the next picture solved this problem, another case we have to fix all column, it is also important in the case of low traction.

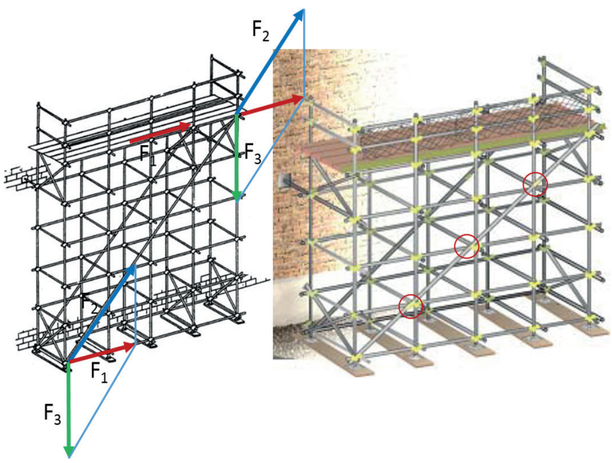


Fig. 6 On the left, we can see a picture of a suggested scaffold from the guide of OSHA standard. On the right, we can see a revised scaffold in a picture of Scaffolding eTools [66] site which is also controlled under the OSHA[4], but the guide of the standard has not changed yet

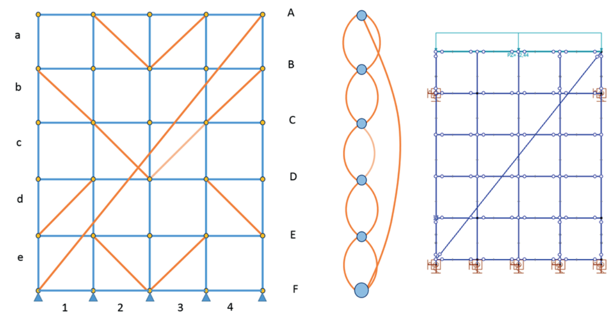


Fig. 7 In the middle, we can see the rigidity graph of the lefthanded 2-dimensional five-story square grid building, the node of the ground floor is bigger than the others. On the right, we can see the finite element model of the 3-dimensional scaffold of the Guide of OSHA [4]

In [16] study the 256 symmetric one and select the bests and the worsts patterns of the total patterns are reviewed. However, we test a four-bay and five-story structure similarly, because of the precedent of the standard of OSHA U.S. Department of Labor [66].

We consider the 2-dimensional 5-story building that we can see on the left in Fig. 7 is simpler than the 3-dimensional scaffold, their FEM designed projection we can see on the right-hand side of this figure.

3.2 The rigidity of the 2-dimensional building

This section will review the methods of determining connection and section properties, followed by examining scaffold and falsework models as 2-dimensional building, finally reviewing scaffold and falsework safety.

Firstly, we give a simple model to decide the rigidity of the ideal structure, where the elements are not deformable.

Let the bracing graph of the 2-dimensional braced building the next:

Definition: Each of the slabs of the stories including the ground floor and the ceiling of the upper story correspond a node, and there will be an edge with multiplicity k in the graph between two nodes if there are k pieces diagonal braces between the corresponding slabs (or upper ceiling).

There is a light colored diagonal brace in the c-th story 3-rd flat on the left picture of Fig. 7. For this reason, there is a light colored edge in the bracing graph in the middle of Fig. 7. Between nodes which correspond to the c-th floor's slab D-th and ceilings of the c-th floor or slab C-th. There is a long brace on the left-hand side building, for this reason, there is a long edge between the corresponding nodes ground node F (larger node) and the ceiling node A.

The next theorem describes the kinematic properties of the braced 2-dimensional n-stories building crosslinked by long diagonals as bracing elements (diagonal as short brace, or real long diagonal as sections between two joints as grid points, whose endpoint coordinate difference may be greater than one as long brace). Similar results are published in [67–73] for periodical frameworks.

Theorem 1: the two-dimensional square grid building using some long diagonals as bracing elements is infinitesimally rigid, if and only if the bracing graph of the two-dimensional building is connected.

Proof: the consequence of the not deformable elements if there is an infinitesimal horizontal displacement one of the slabs (or upper ceiling) then there is the other slab (or upper ceiling) that connect to the former one with bracing elements. Hence, we get to along bracing elements to the ground floor. It is fixed that imply the other slab also fixed. Conversely: if the bracing graph is not connected, then there are at least two components, just one they include the node of the ground. The corresponding slabs of this component will be infinitesimally fixed to the ground. The other slabs can move independently of the ground floor; the framework is not rigid.

Consequence 1: This theorem describes the rigidity of an ideal structure, but inefficient for deciding the displacement in the case of real structure. It is obvious from the result of section second; the displacement depends on the bracing pattern, while the bracing graphs of the 2-dimensional braced buildings are the same in the considered cases. However, this model is a good candidate to decide the safety of the bracing elements of the structure.

3.3 The safety of the 2-dimensional building

The redundancies of the bracing elements are substantially from the safety point of view of the framework [74]. Real frameworks consist of redundant connections. In the earlier section each of the floor there were two bracing elements if one of this element is lost than the others hold the rigidity of the building.

The framework is safety if some of the elements collapse while the remainders have kept the rigid structure yet, i.e., its bracing graph is connected in our case. Similar problems are significant and well-studied optimization problems in graph theory, and network analysis [75].

Let the definitions of the braced safety of the braced building the next one:

Definition 1: The braced structure is s order safety braced if any of the s–1 pieces of bracing elements are ruined then the framework is infinitesimally rigid, and there are s pieces of bracing elements, which are ruined, then the framework is infinitesimally not rigid.

For the braced building, if there are two bracing elements in each story than the building is second order rigid, but not in third order since both of the bracing elements of one of the floor are ruined, then the framework is not rigid. The framework on the right-hand side picture of Fig. 5 is 4-th order safety braced.

The connectedness of the bracing graph of the 2-dimensional n story building characterizes the safety of the bracing structure, but not characterizes the safety of the building, because we assumed that the column and beam are not ruined under the loads. They have to remain unhurt in any cases of loads in our cases.

Theorem 2: The 2-dimensional braced *n* story building is *s* order *safety braced* if and only if the bracing graph is *s*-th order edge connected.

Proof: if the bracing graph is *s*-th order edge connected, then after the catastrophe that ruined *s*–1 pieces of bracing elements there remain least one on each floor that is unhurt. If there is an infinitesimal displacement one of the slabs (or upper ceiling), then there is the other slab (or upper ceiling) that connect the former one with one of the bracing elements that remain unhurt.

If the bracing graph is not *s*-th order edge connected, then there is least two component after the catastrophe that ruined *s*–1 pieces of bracing elements. The corresponding slabs of the components can move independently of each other.

Consequence 2: The 2-dimensional braced n story building using diagonal braces (not allowed long braces) is least s order safety braced if there are at least s pieces of diagonal braces on each floor.

3.4 The real 2-dimensional 5 × 4 building

On the right-hand side of Fig. 8, we can see the FEM model of the OSHA Scaffolding. In this section, we focus on the displacements 5 × 4 buildings. We consider the stiffness of this object to find the bracing pattern that gives the minimal

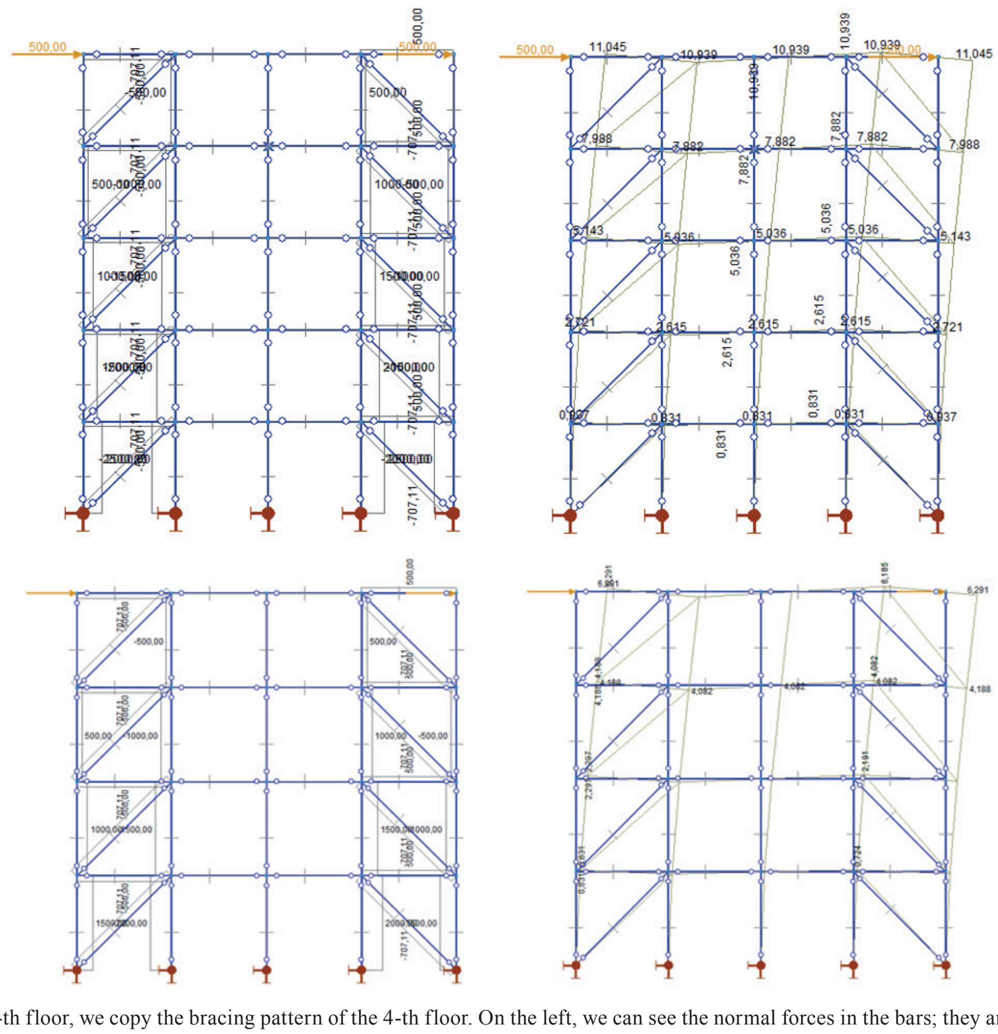


Fig. 8 On the 5-th floor, we copy the bracing pattern of the 4-th floor. On the left, we can see the normal forces in the bars; they are the same in the diagonal bars disregarding the compression or tension, hence the difference of the maximal displacement independent from the displacement that is given from the diagonals

response regarding the horizontal displacements of the upper right corner of the building. These horizontal loads consist of two forces at the upper corners mimicking the wind or seismic loads. As we can see in Fig. 8 and Fig. 9, the given response of the five-story two-dimensional building is nearly two times more in the case of the same loads.

The optimization could show that the mass of the bracing material decreases the height of the building (see question 2, at the end of section 2). The upper parts of the structure became slim the consequence of the decreasing torque. The number of the bracing elements is growing in the lower parts of the building where the torque is the most. If we are disregarding the two diagonal brace per floors assumption than the likely distribution of the diagonal braces would be 3, 2, 2, 1 raising the floors respectively in case of the 4 × 4 building, and 3, 2, 2, 2, 1 in the case of 5 × 4 building. The verification of these conjectures is not to hard work after we find the convenient Script features of the FEM software. The pattern optimization of the case of the cantilever is a very similar object as we can see in Fig. 9, where we can see one of the most stiffer patterns of the 5 × 4 building.

In these cases, the patterns are more similar, than the structures of nature or the architecture like pine trees or the pyramids.

The results of the 5 × 4 building showed that the upper framework in Fig. 9, and Fig. 10 was more effective, with a 25 % reduction in lateral drift or requiring about 75 % less bracing steel.

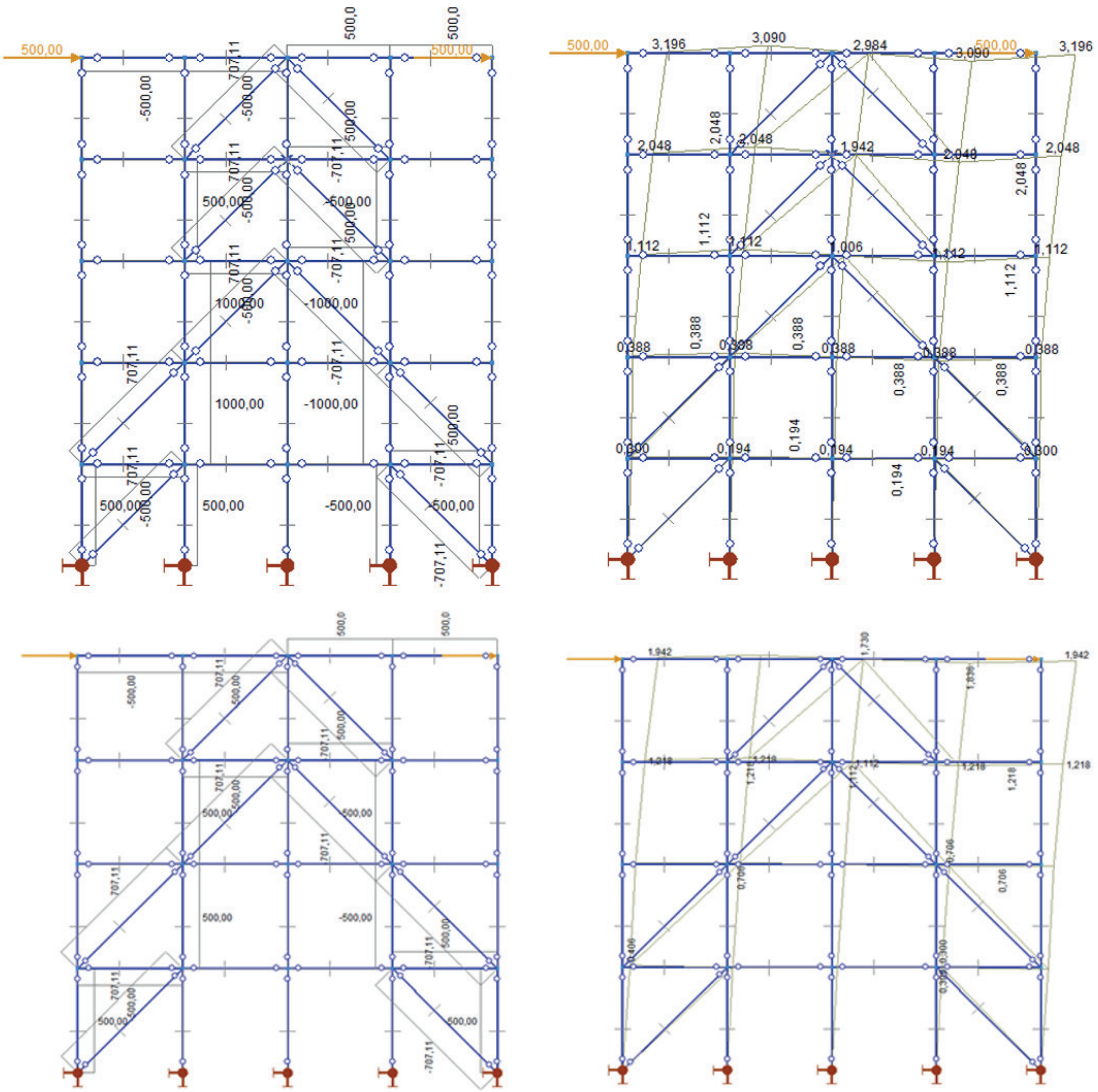


Fig. 9 On the 5-th floor we also copy the bracing pattern of the 4-th floor in case of the stiffest structures. On the right, we can see the normal forces in the bars

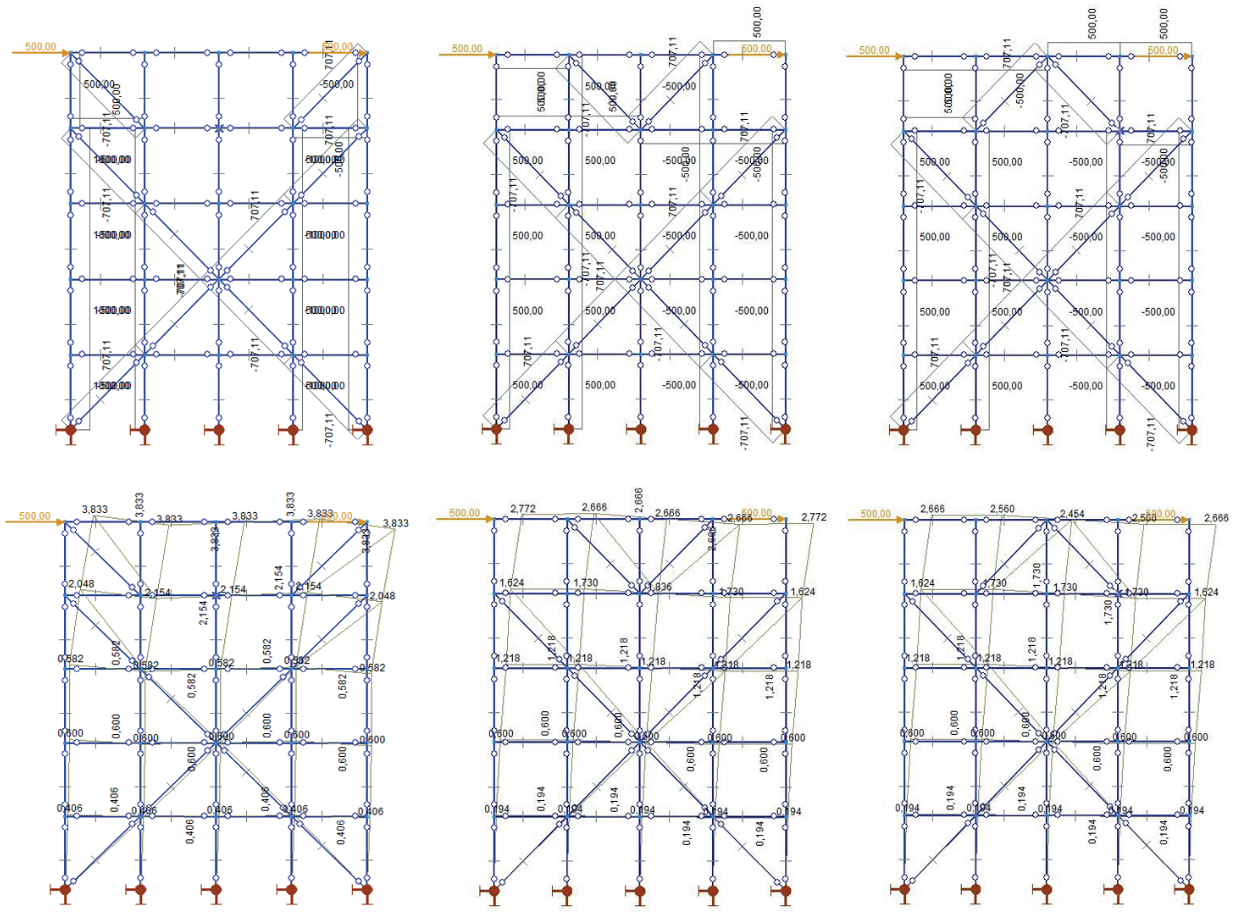


Fig. 10 On the left picture the 5-th floor we also copy the bracing pattern of the 4-th floor in case of one the stiffest structures. On the middle cases show better patterns regarding the horizontal displacement, we can see the normal forces in the bars on the upper row and the exact displacements in the bottom row

The middle patterns of Fig. 9 show a similar trend as the optimization of the cantilever in [65] or the diagrid pattern some skyscraper.

The above result is in the 2-dimensional space, there are few results in 3-dimensional optimizations, so even if we are designing with a 2-dimensional structure and extrude it along the z-axis in the 3-th dimension.

4 Application in the 3-dimensional space

Some of the optimization algorithms are developed to find the optimal member sizes for a given braced frame; they increase the forces of the loads or decrease the size of the members. An appropriate algorithm examines loads of all element and feedback at the weakest links [1, 6, 14, 35, 52, 53, 56, 65, 76, 77]. We could find the optimal bracing patterns also in this manner.

The used brace pattern form in case 3-dimensional building *X*, *V*, *Λ* or *K* capital letters [16] similarly than the stiffest plane pattern in the earlier sections.

4.1. The rolled up the ideal 2-dimensional braced structure

Let us roll up our 4 × 4 braced ideal plane structure into the 3-dimensional space. Hence we get 1 × 1 × 4 spatial cubic grid framework as a 4-story building with bracing elements. The slabs of this framework will be rigid. Similarly, we could roll up an $n \times 4k$ braced plane structure into the 3-dimensional space, and we get a $k \times k \times n$ cubic grid framework as an n-story building, the slabs of this framework will also be rigid. We can present the next theorem for these ideal bar-joint frameworks; we denote them rolled up frameworks.

Theorem 3: If the diagonal braces (least two on each floor) are symmetrical position in the $n \times 4k$ braced plane structure, then the rolled up 3-dimensional $k \times k \times$ n cubic grid framework as an n-story building will be rigid in the case of shear deformation.

Proof: we have to prove there is no shear any of the floor and any of the direction *x* or *y* the consequence of the statement of the rigidity in case of shear deformation.

Contrary put the case that there is shear in one of the floors into the x horizontal direction. In this case, there are no any bracing elements on this floor that prevent the shear, i.e., there is no diagonal for example in the first k column and also there is no diagonal in the third k column in the plane structure. In this case, there is no diagonal in the fourth k and the second k column, since they are symmetrical to the recent columns. Hence, there are no diagonals on this floor; it is impossible because there are at least two bracing elements on each floor. Hence, there are diagonals both of the direction, one of them prevents the shear motions into the direction x or y; its reflection prevents the shear motion into the other direction y or x.

Easier we can find an example in the case of not symmetrical plane pattern when the rolled up framework could be rigid or not. If there are diagonals on each floor of the rolled up framework on the neighboring façade, then it is rigid in case of the shear deformation. What does this mean in case of the $n \times 4k$ braced plane structure? A group of least three diagonals is on the same floor is denoted by alternated, if the integer of their serial numbers divided by k are least three different number. In the cases of concentric force, there could be rotation besides the shear deformation. Hence, the framework could collapse. The next theorem gives a good characterization for the building that has rigid slabs.

Theorem 4: If the diagonal braces (least three on each floor) are alternate position in the $n \times 4k$ braced plane structure, then the rolled up 3-dimensional $k \times k \times n$ cubic grid framework as an n-story building with rigid slabs will be rigid.

Proof: there is no shear any of the floor and any of the direction x or y the consequence of Theorem 3. On each floor, there are fixed least three facades against the share. Hence, the corresponding least two corners are fixed. Hence, the slabs are fixed to each other with the diagonals of the facades.

In the simplest $1 \times 1 \times n$ cases Kaveh and Radics present good results. In the latter paper, we can find a good characterization for the more general n-story building with the tools of combinatorial optimization, in these cases, the slabs consist of bar and joint square grids.

4.2 An almost "real" 3-dimensional building under eccentric load

From 1989, the SZIE Ybl Miklós Faculty of Architecture and Civil Engineering in Budapest have been model The Great Exhausting that was established by Károly Zalka on other international structural spaghetti competition [78]. Towers, columns, cantilevers, beams, or bridges have been designed for these events. The aim of the competition to find the model that the relative fracture loads are highest. The project: Create a tower with 700mm height, with maximal 120mm × 120 mm regular polygon cross-section, and the load on the top of the tower with 50 mm eccentricity. In the 1999 competition, a model of Gábor Drinóczki on Fig. 11 was tested. The mass of the structure was 54,5g and the fracture force 3,13N; this was one of the models, which were fractured upper than the connection of the fracture object. http://mechanika. On the left side of Fig. 11, we can see the model that similar to a rolled up building. Disregarding the reinforced first and upper floor which provides the adequate distribution of the loads we can see the one of the discussed five-story building. We regard the primal framework 5 × 4 Mega X-braced structure superposed the bracing elements of the front part of the construction. We could regard the latter front part of the building as an erected plane cantilever. On the middle picture of Fig. 11, we can see the model during the loading. In the middle part of the structure, we can see the bent vertical elements the consequence of the bending moment that was implied by the eccentrical load.

On the right of the Fig. 11, we can see the structure after the fraction, which could be prevented using some extra bars that hold the bent vertical bar against the deformation. We can see the missing horizontal bars from the building likely the consequence of the decrease of the mass and the missing normal forces in the FEM models. Considering the structure, we identify rigid tetrahedra connected along their edges. These edge connections enable rotations around them. However, these rotations are constrained by the vertical bars that are reinforced in the front of the building.

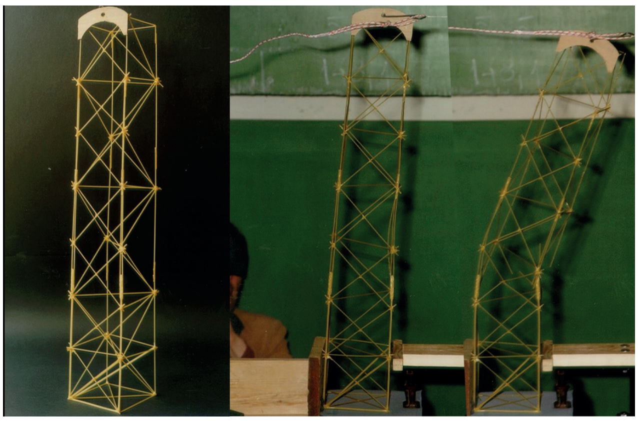


Fig. 11 On the left side, we can see the original model, in the middle during, and on the right after the loading. The left-sided direction of the load is eccentric (the thick cable just for the safety of the model)

Remarkable that the structure of our simple 2d braced framework or the spaghetti model mentioned above is reflected in some new diagrid type tall building as Bank of China Tower, Hearst Tower or Poly International Plaza.

5 Conclusions

The stability of the grid-type braced bar-joint frameworks was considered. We list the contribution of our work to the advancement of the knowledge, technology, and safety, and who will take advantage of our results and in what ways.

5.1 The contributions

A very near published result of scaffold structure based on FEM [16] has been considered. The deformation of them frameworks and the maximal displacement on the upper right corner of the building has been verified. We asked some question at the end of section 2., which leads to a better understanding of the motion of the scaffolds and tall building.

In section 3. we consider the deformation and the maximal displacement of framework 5 × 4, and we have drawn the reader's attention for a false practice guided by the OSHA [4, 66]. We presented the definitions of the braced safety of the braced building and stated a new theorem that characterizes the safety of the building.

We provide a new condition for the rigidity of the rolled-up three-dimensional scaffolding structure applied some further diagonal brace of its faces in section 4.

Considering the real 3-dimensional structures under fracture load, we can connect the behavior our structure with the verified result of [16], contrary to the general method of the practice we show the optimized structures which are at least four times better than those that were used earlier regarding the horizontal deflections.

5.2 The advantages

Who will take advantage of our results and in what ways?

The researchers who will answer the asked questions at the end of section 2, could provide new results which lead to a better understanding of the motion of the scaffolds and tall building.

It is necessary to change the safety engineering practice of scaffolding rising so far the consequence of the described false practice of the OSHA guided scaffold as we consider in section 3.

The structural designer or software designer using the characterization of the rigidity of the braced scaffolding and the two or three-dimensional grid-like bar and joint framework by graph-theoretic results could decrease the complexity of the stability analysis. These results provide useful inputs to the further optimization methods in topology optimization and the design of the tall buildings.

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