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Foldable and Portable Parking Structure Based on MQTT Network and Origami Architecture

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Abstract:
The primary aim of this study was to analyse the forces applied to the origami structure in vacant car parks without vehicles and occupied parking with cars to investigate whether structural durability. The secondary aim was to compare Elliptic Curve Cryptography (ECC)-based on transport layer system (TLS) to complete MQTT network communication and verify the efficiency and suitability of origami structure's smart parking based on MQTT network. We came up with a structure that was inspired from foldable 3D origami shapes and origami parametric architecture. The structure can be connected to an MQTT network offline and works with an efficient algorithm that predicts and makes decisions. We also designed simulations and sensitivity analyses by changing the volume and spacing of the structure. The modelling procedure and determining the optimal solutions is extremely unvaried, therefore the results can be directly applied practically as shown by numerical analysis.

Keywords: Transformable Structures, Portable Architecture, Origami Structure, Smart Parking

Introduction:

Market expansion leads to increased transportation that's linked to one of the vital and inevitable issues in populated cities that's finding appropriate parking areas especially in rush hours. Parking area is an important aspect in distributing products and suppling chain, it acts like a liaison between supply and request in matter of time and space. The Increase of market requirements meet the need for parking lots to provide an adequate space for citizens. Subsequently, mass tracts of land are needed, particularly where the population density rises[1,2]. According to the researches and analyses and cohort studies on two small areas which are similar to each other regarding the area and surrounding population and the conclusion regarding previous studies according to worldwide standards in ideal situation five vacant and free car parks must be considered for each vehicle. It's obvious that this isn't feasible in populated cities[3,4].

According to researches 30% of traffic in populated cities is made by drivers searching for vacant parking spaces, and that a driver spends, an average, 7.8 minutes trying to find an available spot beside the traffic jam the air and noise pollution and the fuel and gas that's been wasted throughout this procedure is a large number and its adverse effects are too serious to be ignored. To be specific, a driver spends about 17-20 hours, meaning 11% of the travel is spent on finding suitable parking spot and approximately each driver spends $345 annually, which means in the US, drivers spend about 72.7 billion dollars searching for a parking spot.[5,6]

The U.S. economy also published a statistic that completes this point. A study on 6000 drivers and 63% of surveys show drivers avoided driving to shopping centres, airports, or gyms, and other destinations due to parking challenges. This number can cause a huge loss of costumers[7,8]. Another study on the capacity of parking spaces assesses the drivers needs and service related and shows the parking area needed according to the formulas and tables, ideal parking area designs that could be convenient for each car there would be 5 vacant spots. This isn't feasible in populated cities because there are area limitations. Annually, several algorithms and new car park ratios are submitted by government with the purpose saving time and decreasing costs by finding the nearest vacant spot, but previous researches were not practical in each and every country[9,10].

Several parking designs were recommended for populated cities and a few are being consumed namely, rotary parking, smart tower parking or smart automated parking towers, or compact automated parking system (CAPs). Such revolutionary designs in parking spaces are more convenient and is more efficient in comparison to traditional car parks and garages. This modern design has a number of advantages such as more cars are accommodated in a smaller space and vehicle theft is no longer an issue and driver security is assured. On the other hand, it has some disadvantages that are investigated in this article[11,12].

The main issue is the variety of electrical circuits and professionals needed to build a smart compact parking it's takes more time and needs more workforce.

This study focuses on two aspects. Firstly, we incorporated a design that addressed space limitation issues through combining origami principles and modern architecture concepts. Incorporating origami is something new, modern and innovative. Parametric origami structures made a revolution in Interior design industry. Such an elegant and distinguished form has become an important source of inspiration for architects and interior designers[13]. Origami-inspired designs are extremely creative and nowadays it's given more attention and more concern because finally it concludes to a compact and low volume structure can be used as an outcome to solve structural and aesthetic flaws and spacing limitations**.** The structure discussed in this paper can be installed in few days and consumed in congested areas. Additionally, this structure is portable, so this smart foldable design has the capacity to be relocated and repositioned to facilitate space in overcrowded spots that mean it could be assembled by an expo and relocated and moved to another crowded place even by an unschooled worker. In this article we calculated the pressure on the beams and pillars and made an investigation on the weight of the structure and a probe was made on feasibility study and the structure was simulated in accordance with Building Information Modelling (BIM) protocols such as E-tabs software[14,15].

Secondly a new connection network in recommended for reservation services that WIFI network isn't needed. users and consumers could connect and use this system offline. MQTT is a lightweight network for transmitting data, simple designed and straightforward and easy to be implemented and we are going to go through it in details and define the algorithm and infrastructure required for this network[16].

The programming part has a priority and timing checking system that could suggest and decide where should the car be placed as this system in fully automated and has no human interference protocols. This system suggests the nearest or furthest parking spaces according to the given timing by each driver that when he arrives or leaves the parking[17].

One of the main limitations in constructing a new building or a smart parking tower is the manufacturing time which takes several months or years and this timing could be reduced by using pre-made foldable structures and could be mounted in any place that's required. All of the business specially in pandemic disease situation are driven towards remote and online reservations and the advantage of this structure is that it can register using online and offline platform as well due to MQTT based network that's being used in this system[18,19]. Using MQTT platform besides the IOT service provides several functional services including parking vacancy detection, real-time and live data for drivers about parking availability, driver guidance for nearest free space, and parking reservation. Moreover, this system gathers the data and uses this data as a reference and in ML procedure it could predict the rush hours[20,21].

We have designed a web application that's connected to main board (Node-MCU board in prototype), ultrasonic sensor and GPS using MQTT network and it has live database that send real-time information. We used state street global advisor (SSGA) modify algorithm, to optimize the appropriation of vacant parking place and MQTT standards to get the faster response time of the system when many users are doing the reservation and payment on the website application. Using the website application has a 4 seconds delay meanwhile the MQTT platform, the delay was decreased to 2 second. [22]

Materials and methodology:

In the last decade origami designs are used to compression and fold objects. One examples of utilizing origami architecture is in solar panels that are mounted on NASA satellites.

In other words, this is origami engineering that is wherever structures need to be reduced and compressed and subsequently enlarged for spatial or functional reasons.

The procedure of folding a 2D surface into a 3D shape consists of three important perspectives for the architectural concept, design and presentation.

- Firstly, folding paper demonstrates a primary design technique to create and shape geometric models, which can be seen as a redundant shape from the 2D drawings to a 3D volume and as a result, folding as a generative process in architectural design is highly investigational, unpredictable, and knowledge based aimed procedure. It's 3D, structural and managerial diagrams give vision into new possibilities of unanticipated and accidental results.
- Secondly origami technique is an effectual, efficacious and material-efficient practical and manufacturing process, that the conclusion is a structural model that can support itself due to the durability and stableness of its folds and can as well be unfolded to enable the production of single parts from flat surfaces for the predesignate structure in extensive and wide rage.
- The third and most important point is the folded model compatibility.

The folding process results in a truly compatible and practical and performative structure that provides an extensive degree of freedom for the architect.

The structure that is considered in this study is Kresling origami pattern, to be specific it's 12-sided volume that each floor is diagonally connected to the layer beneath. As the figure below depicts each of these connections form a parallelogram. (6 parallelograms in each floor and by drawing the diameters it turns into 12 triangles)

This structure is supposed to be foldable to a hydraulic jack is mounted on the diagonal pillars so it could lift up the structure.

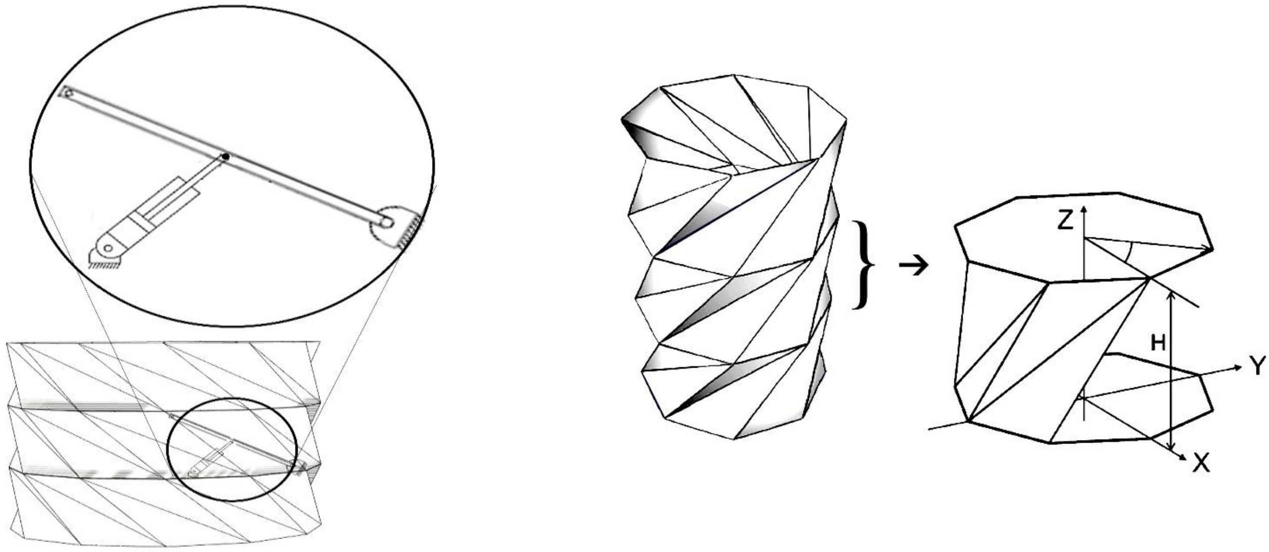

Figure 1: origami structure inspired from kresling origami pattern with hydrualic jack that helps the structure to fold and unfold .

The foldable and portable smart parking consists of three main parts: the elevator, the straddle carriers, and vacant or occupied detection system.

1. Project definition and simulation

In this simulation, the foldable building considered as a 10-storey structure with parking use was analysed and designed. Each floor is 2.8 meters high. To be specific about the location and soil type in this study we decided to simulate on soil type 2 and (allowable soil pressure for foundation) PGA = 0.3 kg / cm [peak ground acceleration].

The structure was designed as a lateral frame bearing system. The building is used as parking lot and in terms of importance, the structure is classified as medium and average importance.

a. Material specifications:

- The height of each floor is 2.8 meters.
- Design parameters are in terms of (kg /m^2) and analytical parameters are in terms of "Kg.f-m.

b. Regulations and reference:

- gravity loading (gravitational load) – sixth article [This topic is about the loads on the building and the loading protocols are determined according to this regulation]
- Lateral loading - AISC-2010 Regulation (LRFD)
- All simulations and designs are according to Iran Standard No. 2800 with ASCE7
- AISC standards for steel detailing AISC-2010 (LRFD)
- Software used for simulation: ETABS software version 18.0.2

c. Soil bearing capacity (kg/cm2) :

Soil bearing capacity was evaluated and based on geotechnical experiments equals to 1.65 kg / cm2.

d. modulus of resilience of Soil:

By Having the permissible Soil bearing capacity calculated in the previous section, modulus of resilience of Soil is determined from the following equation:

$$K_s = 0.4q_{all}(F.S.)$$

In this equation F.S is the reliability coefficient that's 2.75, qall are the permissible Soil bearing capacity and the unit is kg/cm^2 and KS calculation unit is kg/cm^3

$$K_s = 0.4 \times 1.65 \times 2.75 = 1.8kg/cm^3$$

2 Geometrical designs of the foldable structure:

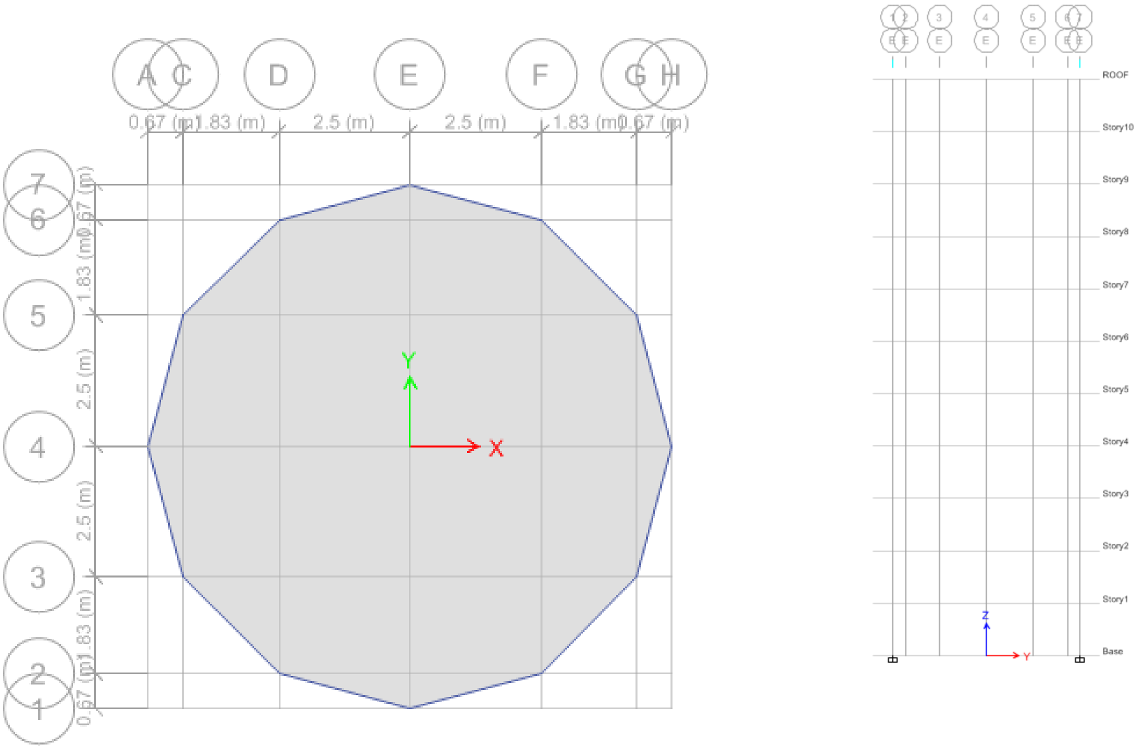

Figure 2: simulating primitive kresling origami pattern design in AUTO-CAD software and defining exacts measurement

Firstly, the plan of the structure is drawn in AutoCAD, and then the dimensions are specified in E-tabs and the elements are drawn and added to the project.

The main plan of AutoCAD drawing is shown in the figure below

- The radius of the circle is 5 and its diameter is 10 meters
- The base shape is a twelve-sided shape and each side is 2.59 meters and the inner angle is 150 degrees.

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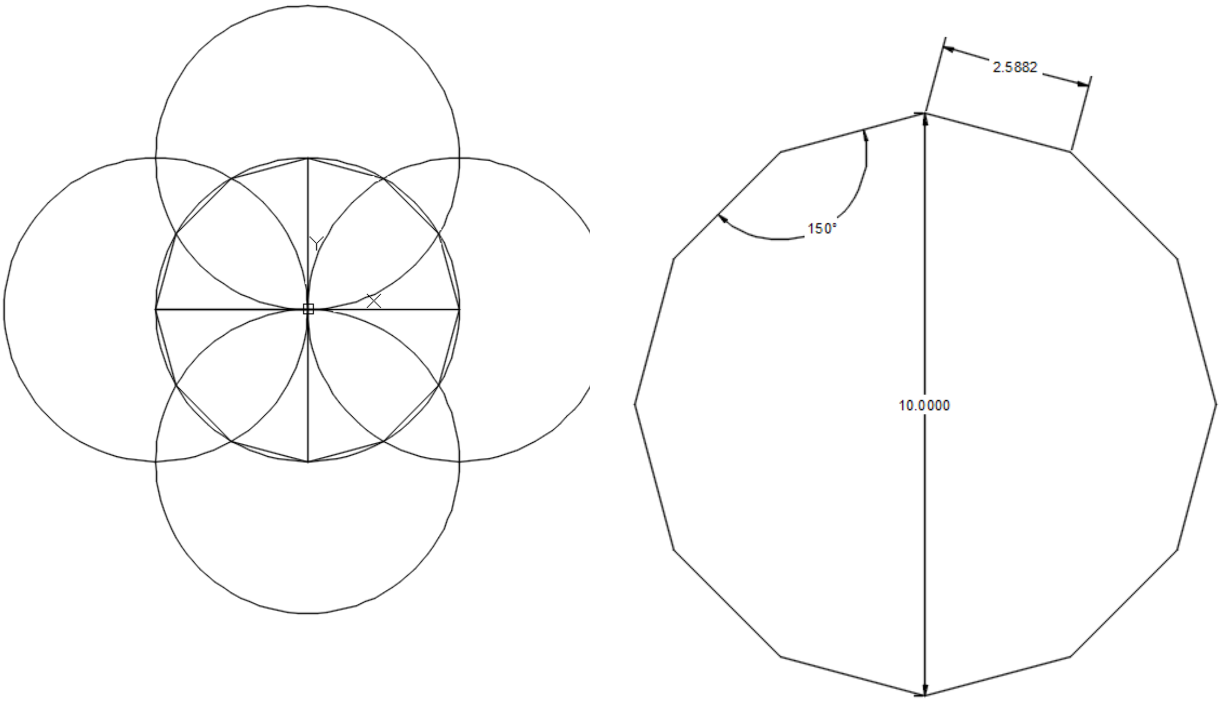


Figure 2: exact measuring of smart parking real world scenario simulation

This structure was inspired from an origami paper tower that the folded and unfolded diagram is shown below (this diagram is designed in rhino software)

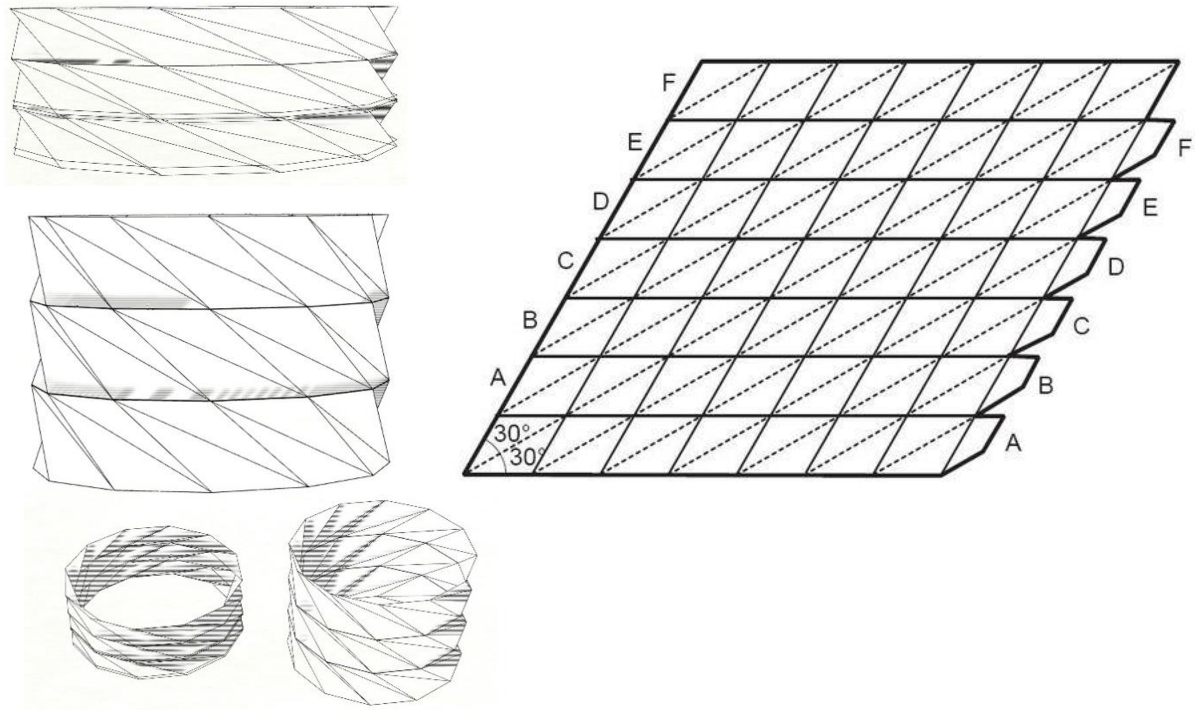
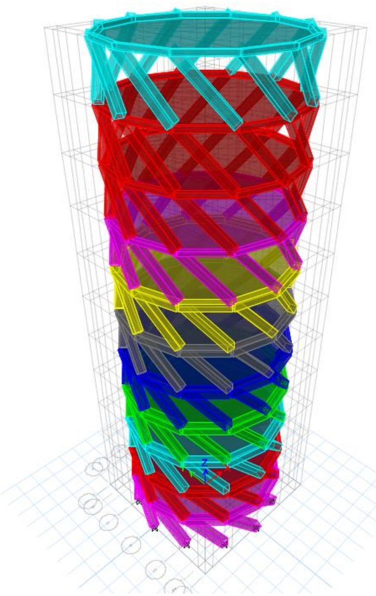


Figure 4: perspective and side view of the structure and 2d printable kresling origami pattern.

2.1 Loading and simulating the structure

In general, the loads on the building are divided into two categories that's gravity loads and lateral loads. Gravitational loads are applied to the building due to the force of gravity on the structure, and for the estimation of these forces, the sixth article of the national building regulations is used. Lateral loads are usually caused by earthquakes, winds, and lateral soil pressures, which are generally predominant in short and medium structures. The AISC-2010 Regulation (LRFD) is used to determine the lateral force of an earthquake.



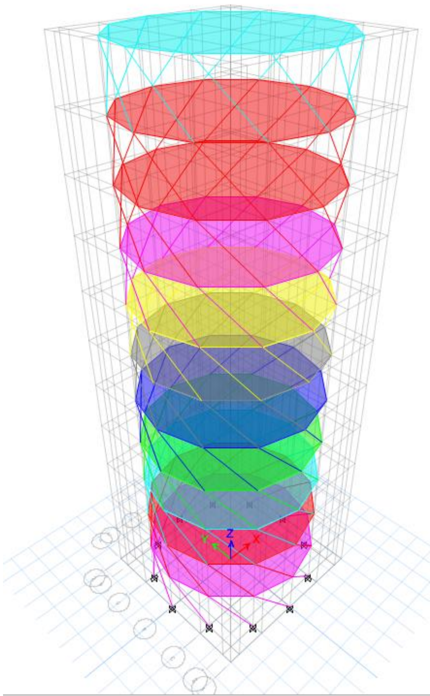


Figure 4: simulating the structure as 3d model and defining the beam and loads- 10 floors - each from has 6 parking slots

2.2 Gravitational loads

To simulate and load this structure the weight of this building, the sixth article of the Iran building regulations has been used and implemented. According to this regulation, the minimum loads that must be considered in the designing a building are determined.

Dead load related to building elements and components:

Dead loads are the weight of the permanent elements of buildings such as beams, pillars, floors, walls, roofs, stairs and rafters, as well as the weight of fixed installations and equipment is classified under this type of loads. To calculate the dead loads, the actual weight of the consumables must be evaluated and for the special mass calculation of materials the sixth article of the national building regulations has been implemented.

2.3 determining live and imposed loads

The main difference between live loads and dead loads is that live loads are unpredictable. Changes in live loads may be over time or depending on location. According to the definition of national regulations, the live loads on the floors are mainly the wide uniform load that is applied throughout the floor. According to Section 6.3.1 of article 6 of National Building

Regulations, live loads are non-permanent loads that are applied to the building while utilizing. These loads are defined according to the type of use of the building or any section of it and the amount that is likely to be applied to it during the life cycle of the building. Minimum amount is determined according to Table 6-3-1 in article 6 of the Iran National Building Regulations. Due to the fact that the live load of the floors is less than 500 kg/m^2 and also less than 1.5 times of dead load, there is no need to comply with the provisions of paragraph 6-3-3 of the sixth article of the Iran National Building Regulations and the imposed load can be distributed throughout the surface.

It is worthwhile to note that in this study, in all of the flats, the imposed load is considered 500 kg/m^2 but in this project, 6 SUV's (sport utility vehicles) with a weight approximately 2 tons have been considered in each floor, that mean each floor is a convenient park space to 6 high ride cars and can be in places in this lot and q total of 60 cars can use this 10 flat structure. This load is applied to all flat and is distributed as live load throughout the whole building.

3 Earthquake loading and simulation

3.1 Calculate the weight of the building:

Computational weight in earthquake force calculations is:

1) Total dead load (including weight of roofs, walls, equivalent load of blades, etc.)

2) Weight of all Permanent facilities

3) A Percentage of live load (for residential buildings, office buildings, hotels, parking lots. this percentage is 20% of live load)

In conclusion, the calculated weight of the building is:

Calculated weight of the building = dead load of the floor + half of the weight of the walls on each floor + half the weight of the walls below each floor + 20% live load

3.2 Seismic loading (earthquake load)

The seismic force affecting the building structure can be calculated using the equivalent static analysis method or dynamic analysis methods. static analysis method can be used if these two conditions are observed in the project.

- Regular buildings with a height of less than 50 meters from the base level
- Irregular buildings up to 5 floors or with a height of less than 18 meters from the base level

The building is regular with a height less than 50 meters from the base level. Therefore, the equivalent static analysis method is used to calculate the lateral force.

Determining the lateral force of an earthquake using the equivalent static analysis method:

3.3 Determine the base cut:

In the equivalent static analysis method where the lateral force of the earthquake is applied back and forth to the structure, the minimum base sheer force of 2800 in each of the building extensions is calculated by the following equation:

$$V = C.W$$

In this equation:

V: Sheer force at base level

W: The total weight of the building (including all the dead load and the weight of the permanent installation) + the percentage of live load and snow load specified in the previous section.

C: seismic coefficient (earthquake coefficient) calculated according to the following equation:

$$C = \frac{ABI}{R}$$

This simulation is done is according to Iran – Tehran standards and according to chart No. 1 Tehran is marked as a high relative earthquake risk.

In this equation according to chart No. 2 A stands for Base acceleration ratio of the design (A=0.35). The structure is considered and simulated in the Iran-Tehran. Tehran is a region with a very high seismicity. The basis acceleration ratio of the design in areas of Tehran with different seismicity

I: coefficient of importance index in building

This building is in the group of medium importance buildings. Therefore, the significance coefficient of the building is l=1.

R: Building behavior coefficient

According to table No 3 The value of the building behavior coefficient for the average moment frame is 5.

$R_X = 5$

B= Building reflection coefficient:

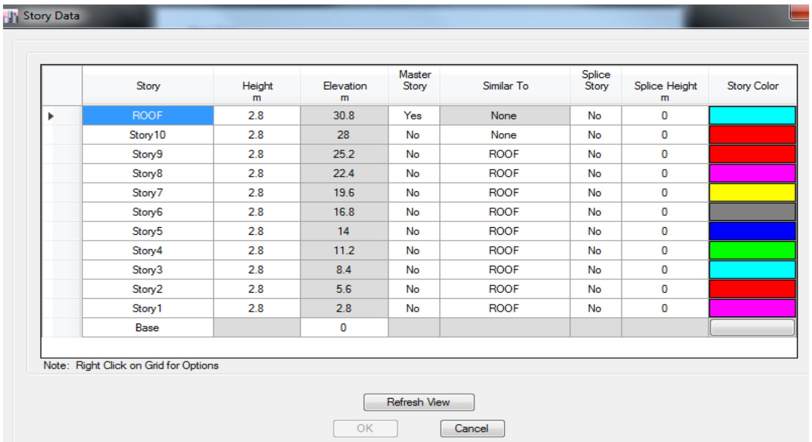
Building behavior coefficient indicates how the building responds to the movement of the earth. This coefficient is determined using the following equation.

$$B_1=S_0+(S-S_0+1)\left(\frac{T}{T_0}\right) \qquad 0\leq T\leq T_0 \qquad (1)$$

$$B_1=S+1 \qquad T_0\leq T\leq T_S \qquad (2)$$

$$B_1=(S+1)\left(\frac{T_S}{T}\right) \qquad T\geq T_S \qquad (3)$$

T: The main rotation time of the building is determined according to the structural system.



Story Data

Story	Height m	Elevation m	Master Story	Similar To	Splice Story	Splice Height m	Story Color
ROOF	2.8	30.8	Yes	None	No	0	
Story10	2.8	28	No	None	No	0	
Story9	2.8	25.2	No	ROOF	No	0	
Story8	2.8	22.4	No	ROOF	No	0	
Story7	2.8	19.6	No	ROOF	No	0	
Story6	2.8	16.8	No	ROOF	No	0	
Story5	2.8	14	No	ROOF	No	0	
Story4	2.8	11.2	No	ROOF	No	0	
Story3	2.8	8.4	No	ROOF	No	0	
Story2	2.8	5.6	No	ROOF	No	0	
Story1	2.8	2.8	No	ROOF	No	0	
Base		0					

Note: Right Click on Grid for Options

Refresh View

OK Cancel

Figure 6: defining roof and base data with exact weigh of the structure.

Due to the fact that the weight of the truss is less than 25% of the weight of the roof, the base level is 30.8 m = H from the roof level.

$\boldsymbol{T_X = 0.08\ H^{3/4} \approx 1.046\ \text{sec}}$

Ts and S: are parameters that depend on the type of land and the seismic hazard of the area. Considering that the soil is type II and considering that PGA = 0.35 is in a relatively high-risk area, the values of T0, Ts, S are as follows:

According to table No.4 that demonstrates land type seismic risk the value of T_0, T_s ,S is as shown below

T_0=0.1 T_s=0.5 S=1.5

Now that T> Ts, we use the third formula to calculate the value of the reflection coefficient (B):

$B_1 = (S+1)(\frac{T_S}{T}) \qquad T \geq T_S$

$$B_{x1} = (1.5+1)(0.5/1.046) = 1.2$$

$$N_X = \frac{0.7}{4-T_s}(T - T_s) + 1 = \frac{0.7}{4-0.5}(1.046-0.5) + 1 = 1.11$$

$$B_X = B_{X1} N_X = 1.2 \times 1.11 = 1.33$$

$$C = \frac{ABI}{R}$$

$C_X = 0.084$

In no case the amount of base cut shouldn't be less than the minimum value below

$V_{min} = .1AIW$

Lateral force distribution at building height:

The base shear force obtained in the previous section is distributed at the height of the building using the following equation:

$$\boldsymbol{F_i = (V - F_t)\frac{W_i h_i}{\sum_{j=1}^{n} W_j h_j}}$$

Regarding this equation:

Ft: lateral force at floor level i

Wi: The weight of floor i includes the weight of the roof and part of its overhead according to Table 1 of standard 2800 and half the weight of the walls and columns that are located above and below the roof.

hi: level i, ceiling height i, from base level

n: Number of floors from base level up

Ft: Additional lateral force on the floor level of floor n obtained from the following equation:

$F_t = 0/07\ TV$

This value should not be considered more than 0.25 and if T is equal to or less than 0.7 seconds, it can be considered equal to zero.

According to Note 28- 2-3 of Standard 2800, if the building has a truss weighing less than 25% of the roof weight, the Ft force will be applied at the roof level, otherwise, the Ft force will be applied at the truss level.

Calculating the earthquake (seismicity) coefficient (C) for X

$$T_X = 1.25 \times 1.046 = 1.31$$

$$C_v = \max \begin{cases} ABT = 0.35 \times 1.2 \times 1.31 = 0.55 \\ 0.1ART = 0.1 \times 0.35 \times 5 \times 1.31 = 0.18 \end{cases}$$

$$C_a = \frac{AB}{2.5} = \frac{0.35 \times 1.33}{2.5} = 0.19$$

3 Modelling procedure

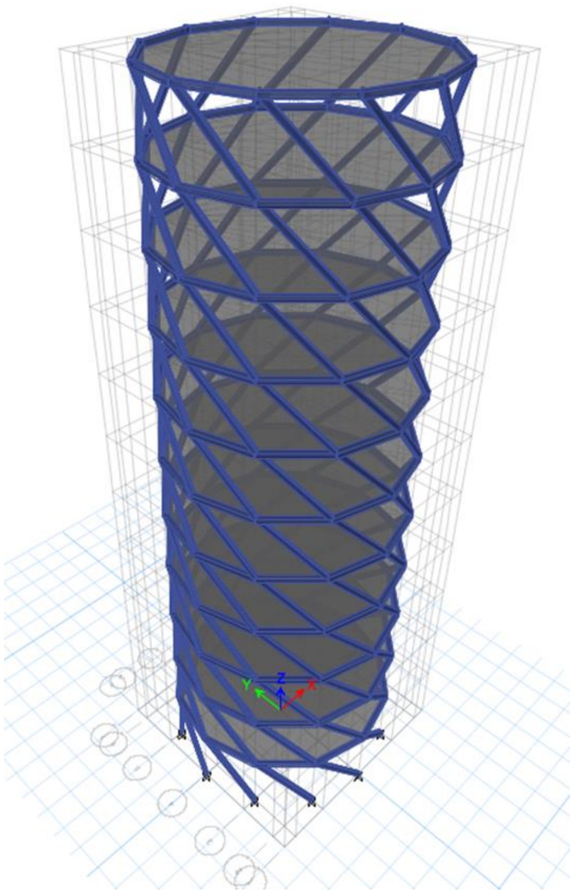


Figure 7: finalizing the design and simulation

4.1 Software simulation

This part gives a brief overview about the simulation process.

- Firstly, specify the exact place of the beams and pillars using the program guidelines and help so that they can be easily defined and specified
- The grid lines is drawn as the figure bellow

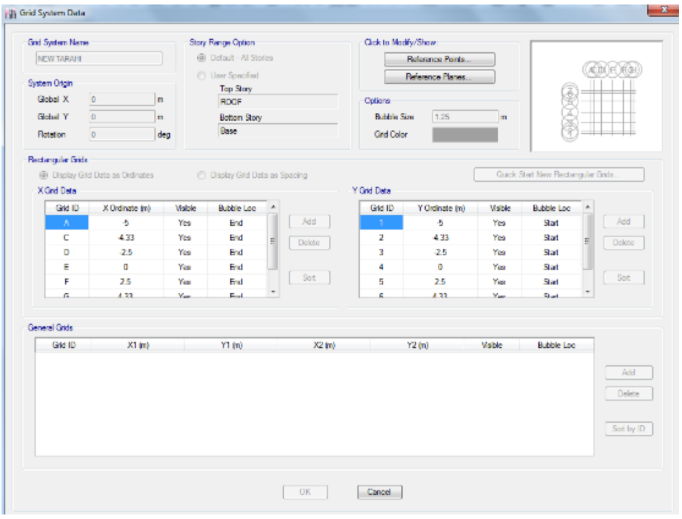


Figure 8: defining horizontal and vertical grid lines

- Then we place the beams and pillars on the grid connection points.

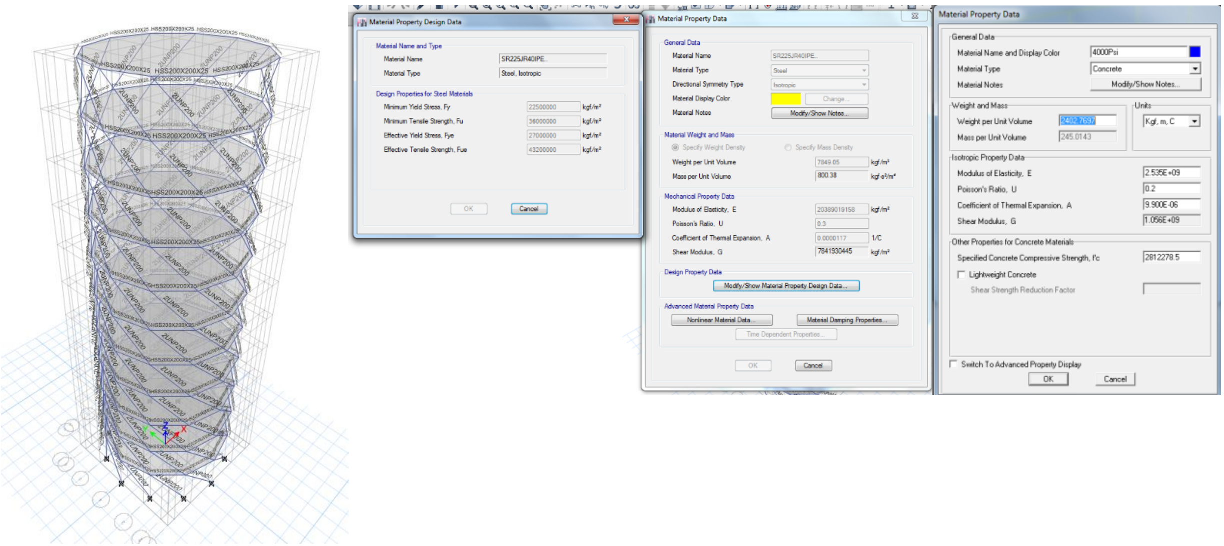


Figure 9: defining material property data and designing beam and pillars on the joints

- secondly, we define the specifications of concrete materials in the software as shown in figure above.

4.2 Specifications of steel materials

In the next step, we define the beam and pillar specifications and use the built-in software menu to complete this procedure

Below is an example of a defined beam and column.

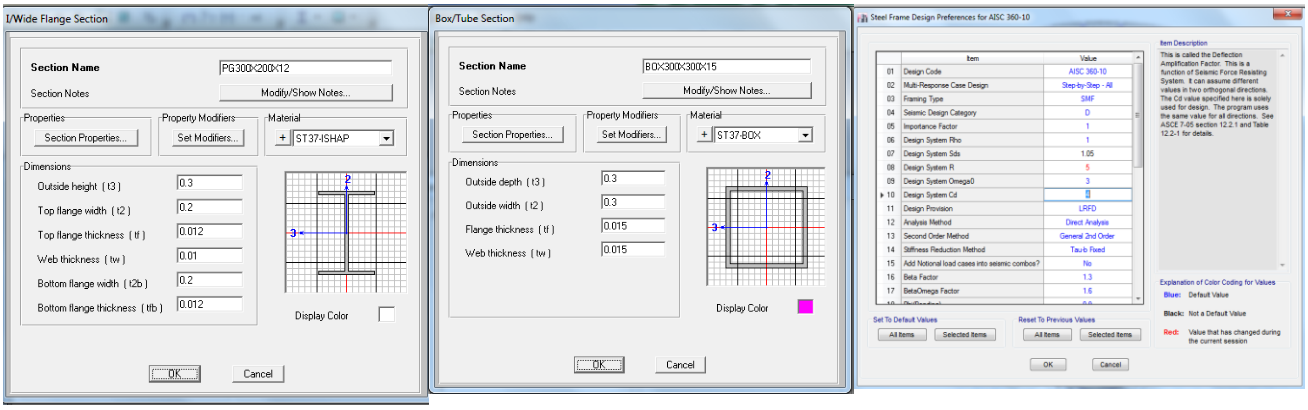


Figure 10: defining box/tube sections and columns and defining thickness and at the end analyzing the results

4.3 Defined beam profile and define pillar profiles

In the next step, we define the loads on the structure and pillars. Dead load and live load have been applied to the structure as shown.

In the last step, we analyze the structure and use the results as shown in figure 10

4.4 software errors are checked and the results are documented

Initially, all modeling and loading were controlled and no modeling problems were observed.

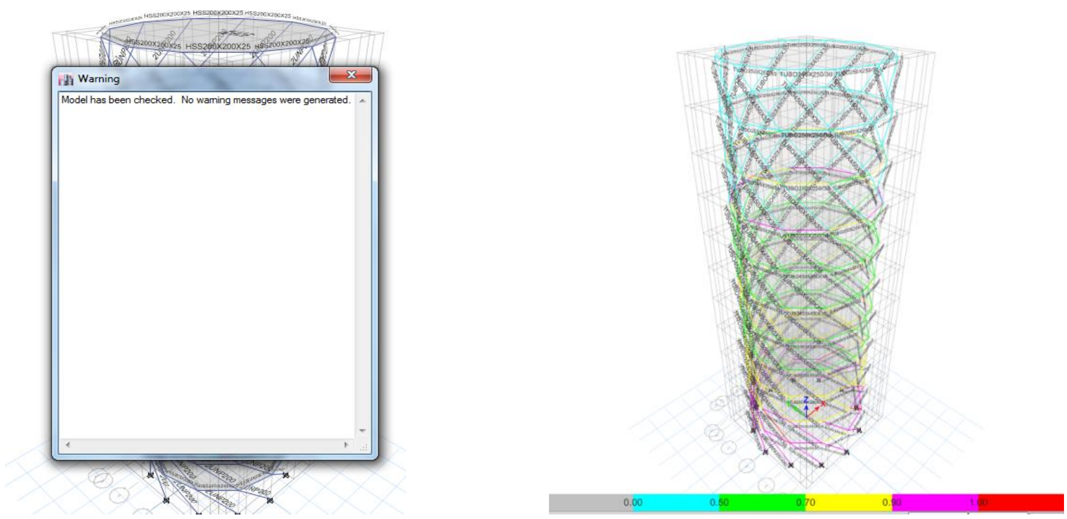


Figure 11: checking and finalizing the values and debugging. The wireframe of the structure is formed

4.5 Designing structural elements

After setting the rules and regulation and different steps of simulation, the desired elements have been obtained.

The structure was controlled in terms of stability and it was stable.

The cross sections are shown and designed in figure 11.

First, we specify the selected pillars for designing and use the manual design software results to perform the desired design element

The element specified in the figure is software designed. The results are presented below.

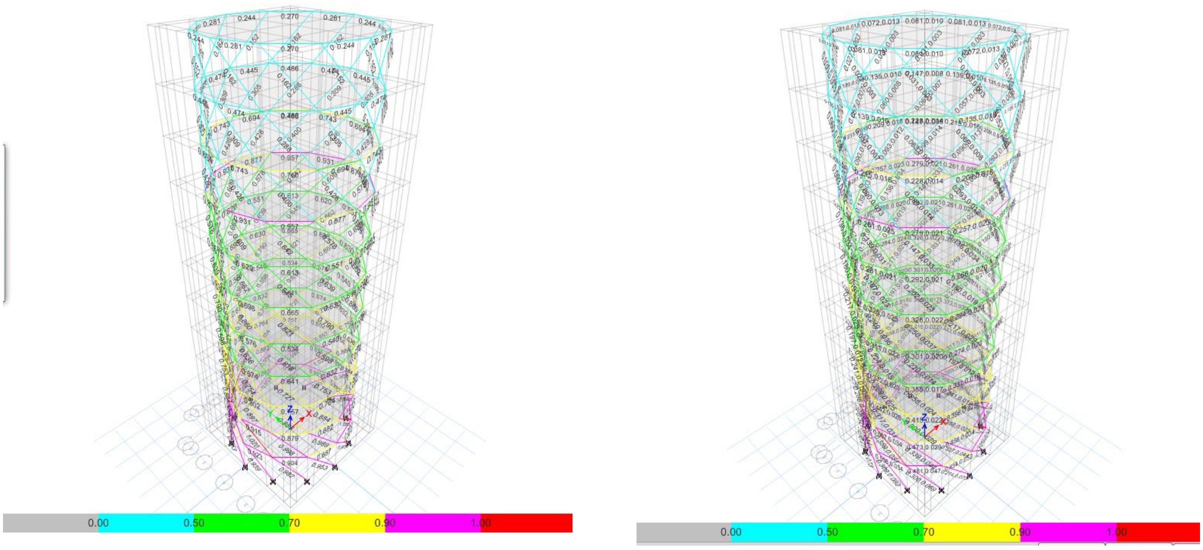


Figure 12: defining pillars in each floor

In the following figure, the shear force control for the sections was applied. Force due to the weight of the structure, the axial force created for each part is shown in the figure below.

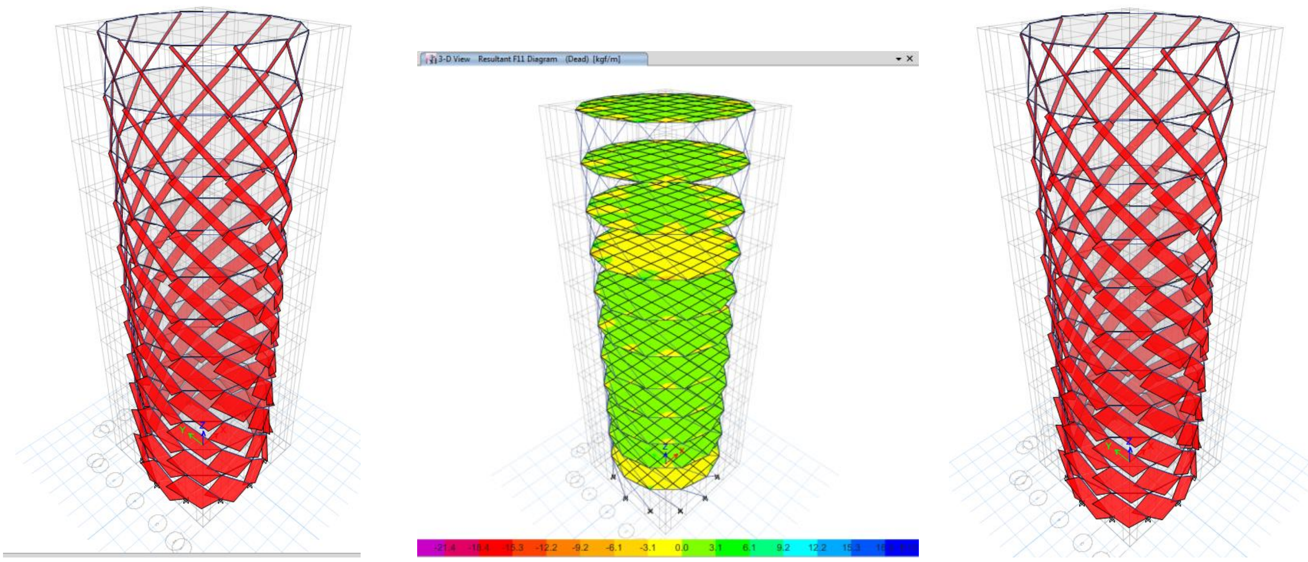


Figure 13: simulating the forces in the floor and pillars

The compressive force due to the weight of the structure itself is shown in the figure below

Due to the weight of the car

Maximum forces toleration influenced by load combination

Because the structure is perfectly symmetrical, the forces are distributed almost uniformly among all members. The figure below shows the columns of the first floor to which the most force was applied.

The maximum amount of force is applied to the beams and pillars on the first floor.

The figure below shows the force ratio for the first floor elements.

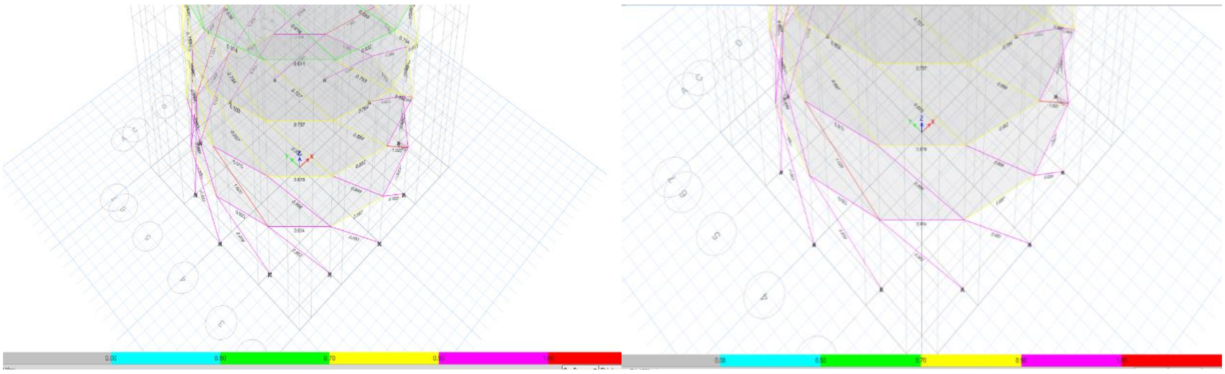


Figure 11: calculating the maximum amount of force applied to the structure (specifically on the first floor)

The force due to the weight of the machine and the weight of the structure itself.

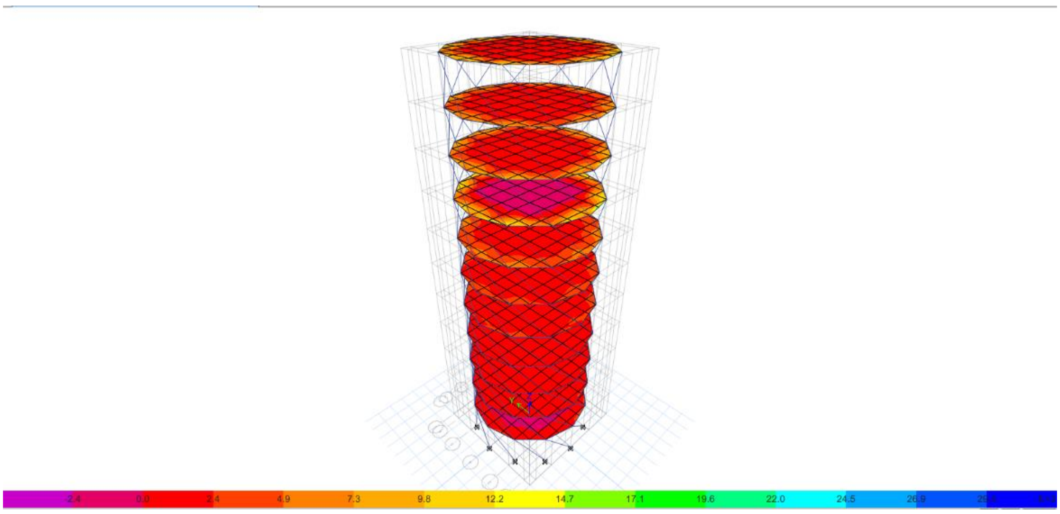


Figure 12: simulating the greatest amount of force applied to the structure in color chart.

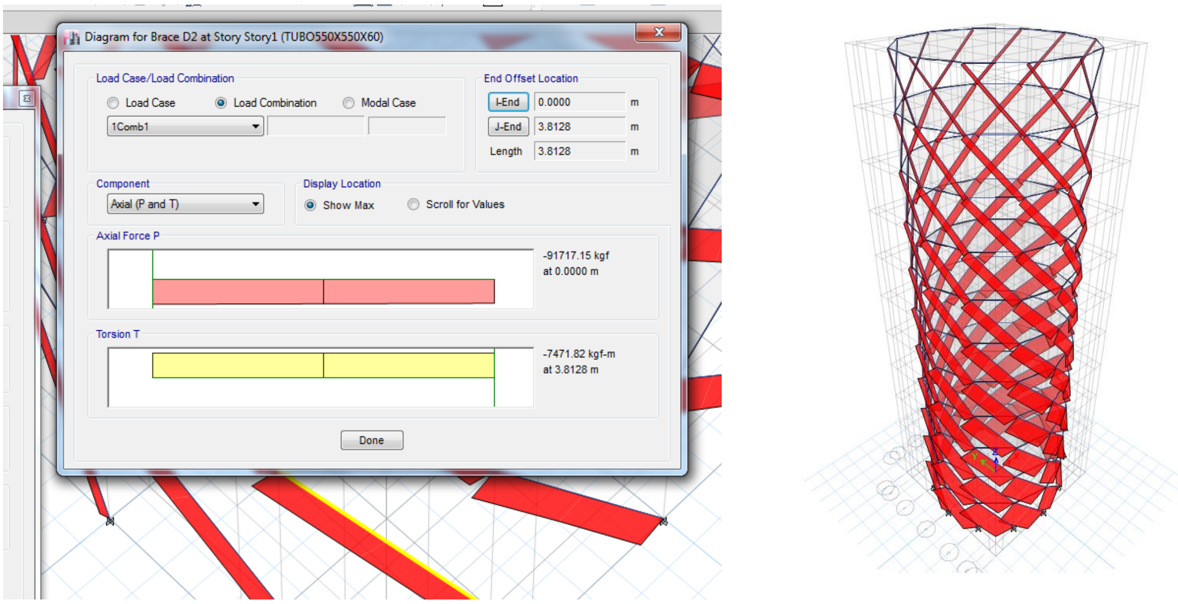


Figure 13: The force applied to the first-floor element

Results and charts:

Table No 1 demonstrates earth quake risks in Iran Arena Based on the "Housing and Urban Development Research Centre "in Iran: Standard No. 2800 with ASCE7

No.	Central arena	State – province	Relative earthquake risk			
			Low	Average	High	Very high
23	Tonekabon	Mazandaran			*	
24	Tang eram	Boshehr			*	
25	Toshk-Absar	Lorestan				*
26	Tosarkan	Hamedan			*	
27	Toye	Semnan				*
28	Tehran	Tehran				*
29	Teyran	Esfehan		*		
30	Tyghar	Southern- Khorasan			*	
31	Tekme-Dash	Eastern Azarbayejan				*

Table No. 2 demonstrates the ratio of the acceleration. In this research Tehran is marked as high seismic risk at a ratio of 0.35

Area	**Definition**	**The ratio of the acceleration of the basis of the design to the acceleration of gravity**
1	Arena with relatively high *seismic* risk	0.35
2	Arena with relatively very high *seismic* risk	0.30
3	Arena with relatively average *seismic* risk	0.25
4	Arena with relatively low *seismic* risk	0.20

Table No. 3 demonstrates average moment concrete frame value and in this article the value of R = 5

Moment frame system	**Special Moment concrete frame**	7.5	3	5.5	200
	average Moment concrete frame	5	3	4.5	35
	ordinary Moment concrete frame	3	3	2.5	-
	Special Moment steel frame	7.5	3	5.5	200
	average Moment steel frame	5	3	4	50
	ordinary Moment steel frame	3.5	3	3	-

Table No. 4 demonstrates value of risk on land types specifically

Land type	T_0	T_1	**Low and medium risk**		**High and very high risk**	
			S	S_0	S	S_0
1	0.1	0.4	1.5	1	1.5	1
2	0.1	0.5	1.5	1	1.5	1
3	0.15	0.7	1.75	1.1	1.75	1.1
4	0.15	1.0	2.25	1.3	1.75	1.1

Final Results: morphogenetic

Table No 5 : results after simulating structure defined in this article and compared the structure in 2 situation . 1- structure weight and forces 2-structure wight and forces with vehicles inside

ETABS 2016 Steel Frame Design

AISC 360-10 Steel Section Check (Strength Summary)

Element Details (Part 1 of 2)

Level	Element	Unique Name	Location (m)	Combo	Element Type	Section
Story1	D2	156	0	03 TASHDID Comb2	Special Moment Frame	TUBO550X550X60

Element Details (Part 2 of 2)

Classification
Seismic HD

LLRF and Demand/Capacity Ratio

L (m)	LLRF	Stress Ratio Limit
3.81285	1	1

Analysis and Design Parameters

Provision	Analysis	2nd Order	Reduction
LRFD	Direct Analysis	General 2nd Order	Tau-b Fixed

Stiffness Reduction Factors

$\alpha P_r/P_{ns}$	$\alpha P_r/P_e$	τ_b	EA factor	EI factor
0.068	0.003	1	0.8	0.8

Seismic Parameters

Ignore Seismic Code?	Ignore Special EQ Load?	Plug Welded?	SDC	I	Rho	S_{DS}	R	Ω_0	C_d
No	Yes	Yes	D	1	1	1.05	5	3	4

Design Code Parameters

Φ_b	Φ_c	Φ_{TY}	Φ_{TF}	Φ_V	Φ_{V-RI}	Φ_{VT}
0.9	0.9	0.9	0.75	0.9	1	1

Section Properties

A (m^2)	J (m^4)	I_{33} (m^4)	I_{22} (m^4)	A_{v3} (m^2)	A_{v2} (m^2)
0.1176	0.007059	0.004777	0.004777	0.0444	0.0444

Design Properties

S_{33} (m^3)	S_{22} (m^3)	Z_{33} (m^3)	Z_{22} (m^3)	r_{33} (m)	r_{22} (m)	C_w (m^6)
0.017369	0.017369	0.021717	0.021717	0.20154	0.20154	

Section Properties --- Unsymmetric Sections

I_{pq} (m^4)	I_{max} (m^4)	I_{min} (m^4)	S_{max} (m^3)	S_{min} (m^3)	r_{max} (m)	r_{min} (m)	α (deg)
0	0.004777	0.004777	0.017369	0.017369	0.20154	0.20154	90

Material Properties

E (kgf/m^2)	f_y (kgf/m^2)	R_y	α
20389019158	22500000	1.2	90

HSS Section Parameters

HSS Welding	Reduce HSS Thickness?
ERW	No

Stress Check forces and Moments

Location (m)	P_u (kgf)	M_{u33} (kgf-m)	M_{u22} (kgf-m)	V_{u2} (kgf)	V_{u3} (kgf)	T_u (kgf-m)
0	-178810.56	-372775.53	42359.9	-161999.23	12655.47	-10354.27

Axial Force & Biaxial Moment Design Factors (H1-1b)

	L Factor	K_1	K_2	B_1	B_2	C_m
Major Bending	1	1	1	1	1	0.343
Minor Bending	1	1	1	1	1	0.544

Parameters for Lateral Torsion Buckling

L_{ltb}	K_{ltb}	C_b
1	1	2.207

Demand/Capacity (D/C) Ratio Eqn.(H1-1b)

D/C Ratio =	$(P_r/2P_c) + (M_{r33}/M_{c33}) + (M_{r22}/M_{c22})$
0.982 =	0.038 + 0.848 + 0.096

Axial Force and Capacities

P_u Force (kgf)	φP_{nc} Capacity (kgf)	φP_{nt} Capacity (kgf)
178810.56	2341842.52	2381400

Moments and Capacities

	M_u Moment (kgf-m)	φM_n (kgf-m)	φM_n No LTB (kgf-m)	φM_n Cb=1 (kgf-m)
Major Bending	372775.53	439769.25	439769.25	439769.25
Minor Bending	42359.9	439769.25		

Torsion Moment and Capacities

T_u Moment (kgf-m)	T_n Capacity (kgf-m)	φT_n Capacity (kgf-m)
-10354.27	377697.98	339928.18

Shear Design

	V_u Force (kgf)	φV_n Capacity (kgf)	Stress Ratio
Major Shear	161999.23	539460	0.3
Minor Shear	12655.47	539460	0.023

End Reaction Axial Forces

Left End Reaction (kgf)	Load Combo	Right End Reaction (kgf)	Load Combo
-200763.32	DSIIS58	-197661.88	DSIIS58

ETABS 2016 Steel Frame Design

AISC 360-10 Steel Section Check (Strength Summary)

Element Details (Part 1 of 2)

Level	Element	Unique Name	Location (m)	Combo	Element Type	Section
Story1	B49	123	2.58801	03 TASHDID Comb2	Special Moment Frame	TUBO500X500X50

Element Details (Part 2 of 2)

Classification
Seismic HD

LLRF and Demand/Capacity Ratio

L (m)	LLRF	Stress Ratio Limit
2.58801	1	1

Analysis and Design Parameters

Provision	Analysis	2nd Order	Reduction
LRFD	Direct Analysis	General 2nd Order	Tau-b Fixed

Stiffness Reduction Factors

$\alpha P_r/P_{ns}$	$\alpha P_r/P_e$	τ_b	EA factor	EI factor
-0.004	-9.638E-05	1	0.8	0.8

Seismic Parameters

Ignore Seismic Code?	Ignore Special EQ Load?	Plug Welded?	SDC	I	Rho	S_{DS}	R	Ω_0	C_d
No	Yes	Yes	D	1	1	1.05	5	3	4

Design Code Parameters

Φ_b	Φ_c	Φ_{TY}	Φ_{TF}	Φ_V	Φ_{V-RI}	Φ_{VT}
0.9	0.9	0.9	0.75	0.9	1	1

Section Properties

A (m^2)	J (m^4)	I_{33} (m^4)	I_{22} (m^4)	A_{v3} (m^2)	A_{v2} (m^2)
0.09	0.004556	0.003075	0.003075	0.035	0.035

Design Properties

S_{33} (m^3)	S_{22} (m^3)	Z_{33} (m^3)	Z_{22} (m^3)	r_{33} (m)	r_{22} (m)	C_w (m^6)
0.0123	0.0123	0.01525	0.01525	0.18484	0.18484	

Section Properties --- Unsymmetric Sections

I_{pq} (m^4)	I_{max} (m^4)	I_{min} (m^4)	S_{max} (m^3)	S_{min} (m^3)	r_{max} (m)	r_{min} (m)	α (deg)
0	0.003075	0.003075	0.0123	0.0123	0.18484	0.18484	90

Material Properties

E (kgf/m^2)	f_y (kgf/m^2)	R_y	α
20388019158	22500000	1.2	90

HSS Section Parameters

HSS Welding	Reduce HSS Thickness?
ERW	No

Stress Check forces and Moments

Location (m)	P_u (kgf)	M_{u33} (kgf-m)	M_{u22} (kgf-m)	V_{u2} (kgf)	V_{u3} (kgf)	T_u (kgf-m)
2.58801	8903.81	265163.61	13160.95	-197428.77	-9490.76	2750.86

Axial Force & Biaxial Moment Design Factors (H1.2,H1-1b)

	L Factor	K_1	K_2	B_1	B_2	C_m
Major Bending	1	1	1	1	1	1
Minor Bending	1	1	1	1	1	1

Parameters for Lateral Torsion Buckling

L_{ltb}	K_{ltb}	C_b
1	1	2.236

Demand/Capacity (D/C) Ratio Eqn.(H1.2,H1-1b)

D/C Ratio =	$(P_r/2P_c) + (M_{r33}/M_{c33}) + (M_{r22}/M_{c22})$
0.904 =	0.002 + 0.859 + 0.043

Axial Force and Capacities

P_u Force (kgf)	φP_{nc} Capacity (kgf)	φP_{nt} Capacity (kgf)
8903.81	1805856.65	1822500

Moments and Capacities

	M_u Moment (kgf-m)	φM_n (kgf-m)	φM_n No LTB (kgf-m)	φM_n Cb=1 (kgf-m)
Major Bending	265163.61	308812.5	308812.5	308812.5
Minor Bending	13160.95	308812.5		

Torsion Moment and Capacities

T_u Moment (kgf-m)	T_n Capacity (kgf-m)	φT_n Capacity (kgf-m)
2750.86	266856.47	240170.82

Shear Design

	V_u Force (kgf)	φV_n Capacity (kgf)	Stress Ratio
Major Shear	197428.77	425250	0.464
Minor Shear	9490.76	425250	0.022

Chart no. 2: results after assembling the structure and it's fully occupied calculating the weight of the structure and vehicles and checking its stability

Finally, in these sections of the structure that we studied we finalized the results and presented the table below. In this Excel tables, the force applied to each element is given for the combination of different loads. (a part of excel file is copied)

Discussion:

With the growth of number of vehicles in cities, finding a free parking spot in crowded areas has become big issue for drivers. It is possessed in common between drivers to drive for hours and circle in a parking lot for vacant space. These cars lead to an average 30% of the traffic in congested areas. This extra traffic results rise to external social problems, such as traffic congestion, fuel waste, car accident and air pollution. Our project had architectural goals as well as programming aspects that and fortunately we could overcome this two main point in our project, in other words in this article we designed a structure that's inspired from origami shapes and it could be deployed in any situation and crowded areas. In this paper we have proved that origami architecture could be taken to a new level. The building is design and all of the forces are calculated shown the structure is fully stable without any infrastructures.

On the other hand, our second result was the MQTT offline platform that was designed for this structure and the consumers could connect to this system and do the reservations. in this article we proved that this platform is safer and even saves more time.

In this study, an algorithm has been generated for automated parking systems using, through extensive numerical and theoretical analyses, which concludes time complexity reduction faced during parking vehicles in automated parking spaces. The speed efficiency of the algorithm and decision making was evaluated upon performing numerical analyses in a prototype model. As mentioned before most smart parking systems all over the world have similar algorithm and structural models as the model that has been defined in this article, the system would be suitable for many countries addressing and resolving the problems associated with parking spaces.

To be more specific in the architectural part, our aim was to design a structure as a smart parking for temporary usage that can be constructed by unschooled worker. This structure is designed in a way that it could be adaptive to solve our size and space limitations.

In terms of programming researches, our aim was to find an algorithm between the origami parametric designing and building formulas, specially: how to validate and declare a design into definitive and clear rules that are relying on inconstant parameters. All of the calculations were made as a normal structure to examine it stability.

In this paper we consider a new way for designing and building up new pre-made structures in short time that could be foldable and portable Modern architecture in the answer to this question

The case study and the results proved that this design and structure is feasible and stable and according to geometric principles and the data analysis it can maintain enough pressure and it won’t collapse. Furthermore, approaching the design this structure that weighs about 1.5 ton and in folded state it’s about 1.5 floors high and the un folded state in as tall as a tower and hold 75 cars.

Furthermore, folding strategies that describe the constructional laws and material attributes results a sustainable architecture due to a accurate approach, both in the outcome as well as in the design procedure. An adaptive architecture, depending on these perspectives, could have a responsive action to external changes and internal demands

The advantages of this structure are that it solves the space and timing limitation on the other hand, the disadvantages are that this structure is portable and it doesn’t have any foundation so obviously this structure can’t be built very high with large number of vehicles similar to smart parking towers.

According to chart no. 1, we simulated the structure with exact measurements and in 10 floors and real height and calculated the force applied and feasibility and stability and as shown this structure won’t collapse when its vacant. bellow chart no. 1, we calculated the weigh hand the forced applied to the structure when the parking is completely occupied and full that means the weight of the structure in addition to weigh of 60 average vehicle is calculated and as shown the structure is stable. To be certain about the structure the earth quake simulation has also been applied to this structure and fortunately it passed the test.

According to the programming results it might be interesting to know, when conditions are permanent and without any crisis, using machine learning algorithms for prediction to spot vacant places is not necessary. That means Since machine learning is expensive, if it is not needed, it shouldn’t be implemented. On the other hand, if we have a serious traffic condition and parking space limitation it is clear that ML algorithms can add great value to a smart parking system. Data that’s transmitted from parking sensors can be combined with previous knowledge demand to accurately predict future availability. This acts as a unique value-add to real time information.

Future research will focus on building higher origami structures and solving the foundation issue to it could be compatible with normal tower. The second part of this paper was about MQTT network that we implemented to receive and transmit data instead of WIFI network and throughout this paper we showed that this network has couple of advantages is the delay timing that’s decreased while using the application and on the other hand by implementing this network the system and application can be used and consumed offline.

This new network like any other new technology has some disadvantages, that’s the infra-structured needed for this network.

The combination of origami and architecture can have an influence on varioust aspect and furthermore, the technology needed is to some extend easy to supply and implement and sustain.

Conclusion:

The simulation and prototype have highly confirmed the claimed points and passed the flexibility, stability test and from the aesthetical point of view it is hoped that the present structure can revolutionize the way in which we currently conceive buildings.

Future work of this project involves deployment prototyping a larges model of and examining in extensive level which means that real-time parking data can be collected on a pre-defined out going basis. As the dataset collects its information, machine learning function and prediction procedure will take place.

The second main action that could be taken in near future researches the work may be broadened to develop the architectural and framing structure view point more methodical and systematic that could hold larger number of vehicles. Moreover, if the system can be made cost effective then it can be hoped that the system may be administered on a large scale and deployed in cities.

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