Seismic Retrofit Design of Central Control Building in an Oil Complex with T–Shaped Concrete Shear Walls from Outside of the Building

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SUMMARY:
The central control building in an oil complex in south of Tehran city with concrete structure consists of two main stories and one half stories. The dimensions of first and half floor plan is 14.7*19.7 m^2 and for basement is 13.8*14.2 m^2. The height of building is 9.1 m and in longitudinal direction it has four spans of 4 m with two of 1.85 m cantilever. In transverse direction it has two spans of 7.1 m. In order to increase the lateral resistance of the building, the T-shaped concrete shear walls connected to the columns from outside of the building have been used. For the building analyses, two levels of hazard, and two levels of performance such as life safety and collapse prevention were considered. The acceleration of the building due to earthquake with probable occurrence of 10% in 50 years (475 years return period) was 0.38g and also for earthquake with probable occurrence of 2% in 50 years (2475 years return period) was 0.63g. Due to existence of irregularities in torsion stiffness, the dynamic analyses with site acceleration spectrum were done by ETABS2000. After determining the earthquake forces and applying them to the structure, the responses such as element capacities, drifts and rigidity of the diaphragms were controlled. In this case the demand capacity ratios (DCR) for each element and for T-shaped concrete shear walls were determined and were found that the behavior of shear walls is flexural. After analyses and checking the highest approved criteria, it was found that the designed T-shaped concrete shear walls were satisfied. Also, the seismic behaviour of foundations including T-shaped concrete shear walls was controlled by SAFE2000 software. The approved criteria for soil and foundation interactions with two levels of hazard were controlled and was found that for different load combinations, the soil stresses were less than the allowable values and also the shear and flexural capacity of existing foundation were in a suitable condition and acceptable.

Keywords: Seismic Evaluation, T-shaped Concrete Shear Wall, Retrofit Design

1. INTRODUCTION

According to the annual information, every year more than 2000 earthquakes occur in the world from which in average each year one earthquake occurs with the magnitude of 6 Richter and within past 80 years before, ten earthquakes, occur with the magnitude of 7 Richter or more. Recent researches show that many damages in buildings during the earthquakes are the cause of using old codes and regulations in their designs. The shear mode failure of these buildings is due to the weak ductility of the elements with sudden brittle crack. In this paper the seismic evaluations of a typical control building are implemented using recent Iranian national codes and instructions such as Iranian Instruction for Seismic Rehabilitation of Existing Buildings (No. 360) and Iranian Code of Practice for Resistant Design of Buildings (Standard No. 2800).

2. EXISTING SITUATION OF CONTROL BUILDING

The central control building is a concrete structure resisting frame with two and half stories. The half story is devoted for transporting the connecting cables to the control equipments. The area in the first story is 19.7*14.2 m^2 and in the basement is 14.2*13.8 m^2. The height of building is 9.1 m. Also, a basement floor is 2 m below the ground surface. In general the structure is made of 3 types of rectangular beams with dimensions of 30*35, 38*50 and 50*80 cm^2 and because of connectivity of beams and slabs; the existing beams behave as a T- shape beam. The existing floor slab is a two way slab with 14 cm thickness and the column sections is rectangular with the dimension of 45*60cm^2 and 45*45 cm^2. Fig. 1 shows the elevation of the central control building. In Fig. 2, 3 and 4 the plane and the section of the building are shown. According to the national regulations of loads imposed on buildings, the building is regular in plane and elevation.

Figure 1. Elevation of the building

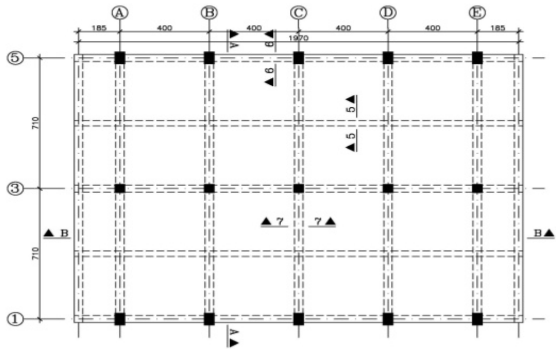

Figure 2. Framing plan at elev. +2.85

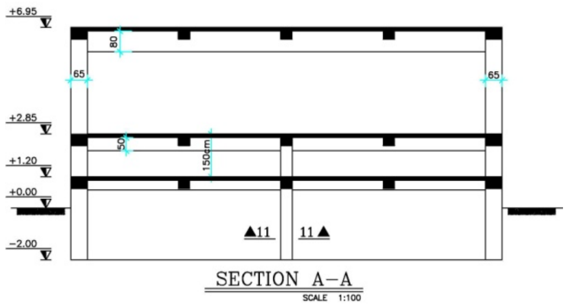

Figure 3. East & West Elevation

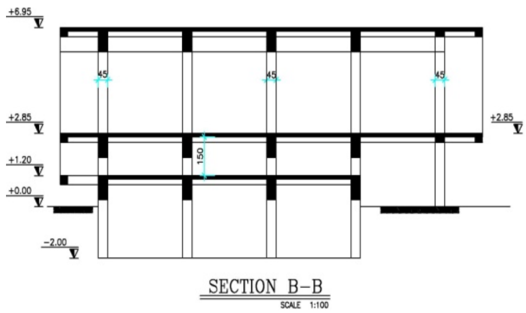

Figure 4. North and South Elevation

According to the site visits, gathered data and needs of client, the optimum retrofitting target is selected. Therefore, performance level of life safely (LS) at hazard level 1 and collapse prevention (CP) at hazard level 2 are determined. Moreover, geotechnical tests for finding the allowable soil pressure and soil modulus of elasticity is determined. According to the type of soil which consists of clay relative stiff, the allowable soil pressure under dead and live loads for single and combined footing is 1 kg/cm^2. According to the Instruction No. 360, as the existing footings are single and combined, the expected bearing capacity of the soil for safety factor of three is determined as 3 kg/cm^2, related to the site evaluation. Beams and columns concrete compressive strength are 250 kg/cm^2 and for foundation it is 280 kg/cm^2. The yield stress of reinforcement for beams is 3314 kg/cm^2 and for columns are 2205 kg/cm^2.

3. EARTHQUAKE RISK ANALYSIS AND ELASTIC DESIGN SPECTRUM

According to the risk analysis studies, the seismic evaluation of central control building is done by using acceleration design spectrum. The design acceleration for earthquake hazard level 1 (earthquake with the probable occurrence of 10% in 50 years and 475 years return period) is determined as 0.38g, and the design acceleration for earthquake hazard level 2 (earthquake with the probable occurrence of 2% in 50 years and 2475 years return period) is determined as 0.63g. According to the Instruction No. 360, it is noted that the acceleration spectra from specific site spectrum should not be less than the acceleration obtained from Standard No. 2800, with 5% damping. The site design spectra with hazard level 1 and 2 are shown in Fig. 5 and 6.

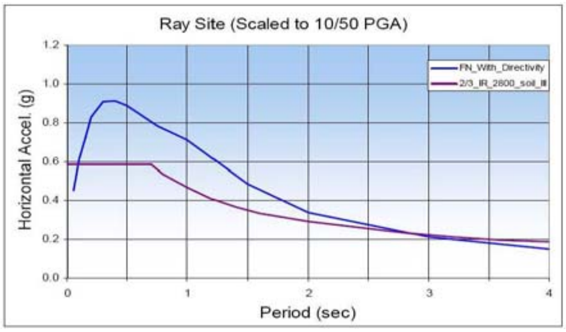

Figure 5. Specific site design spectrum (hazard level 1)

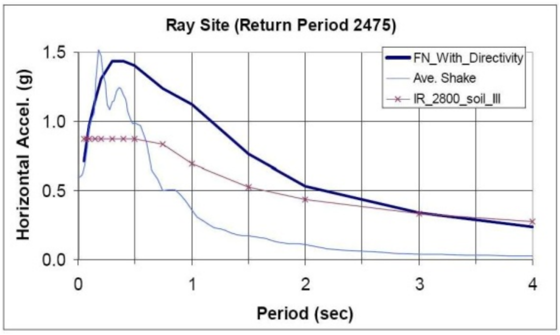

Figure 6. Specific site design spectrum (hazard level 2)

4. THE PROPOSED RETROFITTING DESIGN

For modeling the structure, the ETABS software is used. After modeling the existing structure and investigating the accepted criteria according to the Instruction No. 360, it was found that the structure should be retrofitted. In this research, for retrofitting the structure, the concrete T-shape shear walls connected to the northern and southern columns are used.

Fig. 7 and Fig. 8 show retrofitting plan and typical detail of retrofitting section, respectively.

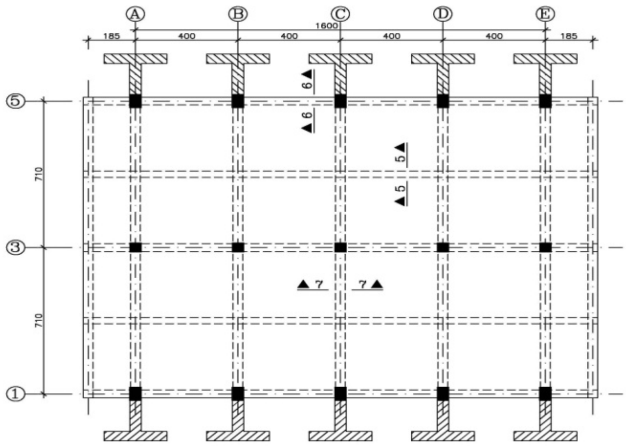

Figure 7. Retrofitted plan at half floor ceiling

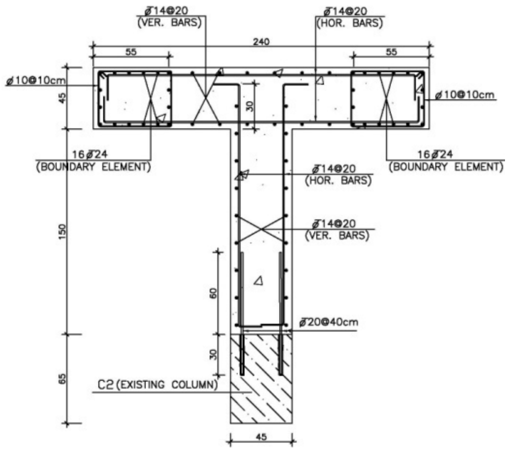

Figure 8. Concrete shear wall connected to the column

5. EVALUATION AND CONTROL OF APPROVED CRITERIA AT HAZARD LEVEL 1

5.1. Modelling

As stated before, analyses of the structure are done by using ETABS2000 software. Vertical and lateral resisting system in two directions is moment resisting frame, in which concrete T-shape shear walls are connected to the northern and southern part of the building. Again, as the behavior of the roof slab is similar to the composite beam, according to the Instruction No. 360, the beams should be modeled like T-shape beam in the original model.

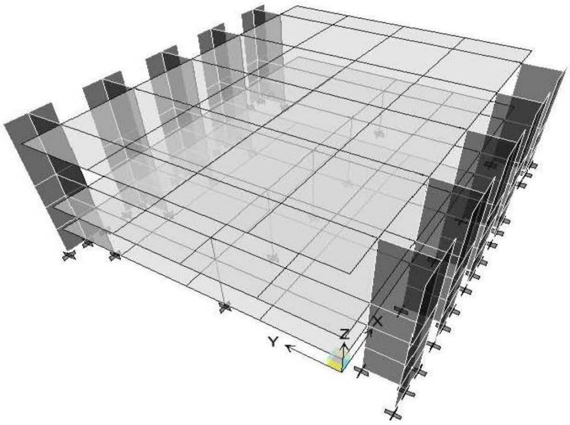

Figure 9. Three dimensional retrofitted building

5.2. Earthquake calculation using linear static method

In linear static analysis, the shear force is calculated according to the following method. Details of calculations are shown in Table 1. The coefficient C_3 is supposed to be unity and after analysis it will be modified. According to the Standard No. 2800, weight of structure (W_e) consists of dead load plus 20% of live load.

$$V=C_1C_2C_3C_mC_aW_e \tag{5.2.1}$$

Table 1. Building shear force using linear static method

Soil Type	a	h(m)	T (sec)	T_0 (sec)	T_s (sec)	S	$S_{a,10\%}$	C_1	C_2	C_3	C_m	W_e	$V_{10\%}$
3	0.05	9.55	0.272	0.15	0.7	1.75	0.909	1.36	1	1	0.8	1150	1138

After primary analyses and finding displacement of each floor central stiffness (δ_i), in longitudinal and transverse direction, in addition to determination of floor shear force (V_i) in longitudinal and transverse direction, the stability coefficient (θ) for each floor is determined according to the Table 2. It is shown than the maximum value of the coefficient is 0.003 and is less than 0.1. The distribution of the lateral forces on the building is shown in Table 3.

Table 2. The values of stability coefficient at hazard level 1

STORY	P_i (ton)	δ_{xi} (cm)	δ_{yi} (cm)	V_{xi} (ton)	V_{yi} (ton)	h_i (cm)	$\theta_{xi} = (P_i\ \delta_{xi})/(V_{xi}\ h_i)$	$\theta_{yi} = (P_i\ \delta_{yi})/(V_{yi}\ h_i)$
Roof	588	1.24	0.37	627	627	410	0.003	0.001
Second	1046	0.33	0.11	985	985	165	0.002	0.001
First	1342	0.62	0.16	1138	1138	380	0.002	0.000

Table 3. Distribution of lateral forces on the building at hazard level 1

STORY	W_i (ton)	h_i (m)	$W_i\ h_i^k$	$(W_i\ h_i^k)/(\Sigma\ W_i\ h_i^k)$	$F_{xi} = F_{yi}$	
Roof	440	9.55	4202	0.55	627	627
Second	440	5.45	2398	0.31	358	358
First	270	3.8	1029	0.13	153	153
SUM	1150		7626		1138	1138

5.3. Method of analysis selection

In order to use the linear static analysis, the following steps should be controlled:

- Control of the main period of the building: T=0.272 (sec) < 3.5Ts = 2.45 (sec) which is correct.
- Control of the plan dimension: The different dimension of the plan in the floors should be less

than 40%, which is correct.

- Perpendicular lateral resisting system: The building should have two lateral resisting systems.
- Irregularity control in torsional stiffness: The ratio of lateral relative displacement in each floor and each direction to the height of storey should be less than 1.5.

The irregularity control for applying accidental torsion is shown in Table 4.

Table 4. Irregularity control in torsional stiffness

STORY	$Drift_{max}$		$Drift_{avg}$		$Drift_{max}$ / $Drift_{avg}$		($Drift_{max}$ / $Drift_{avg}$) < 1.5	
	x	y	x	y	x	y		
Roof	0.0031	0.0009	0.0026	0.0009	1.18	1.06	O.K.	O.K.
Second	0.0036	0.0009	0.0020	0.0008	1.83	1.12	N.G.	O.K.
First	0.0023	0.0007	0.0015	0.0006	1.54	1.24	N.G.	O.K.

As it is shown in the Table 4, the building in second floor and there in x-direction has irregularity in torsional stiffness, therefore the liner static method for analyzing the building can be used, and linear dynamic method for building evaluation is used.

5.4. Linear dynamic analysis

The number of vibration modes in dynamic analysis should be selected in such a way that the sum of cumulative participated masses for each excited earthquake direction be at least 90%. In addition in each direction at least three first vibration models and at least all models with periods greater than 0.4 second should be selected. Therefore seventeen vibration modes for spectrum analysis are used and the results with the complete quadratic combination (CQC) are presented. Also the effect of earthquake in two perpendicular directions is considered on the structure. Because of the common columns between two or more lateral resisting frame in two perpendicular directions, 30% earthquake forces in perpendicular direction for load combination is considered. The distribution of lateral forces in the height and plan of the building in terms of acceleration, mass distribution for each floor is done by dynamic analysis, the amount of forces and displacement obtained from linear dynamic analysis should be multiplied by the coefficients C_1, C_2, and C_3 according to static method. These coefficients for modeling of the building is applied in the earthquake load combinations, and the effect of P-Δ with the coefficient of C_3 is applied According to the results the floor diaphragm in two direction is rigid.

5.5. Gravity and lateral load combinations

Two types of gravity load combinations are suggested:

$$Q_G = 1.1(Q_D+Q_L) \tag{5.5.1}$$
$$Q_G = 1.1(Q_D) \tag{5.5.2}$$

In order to determine the forces and displacements in the members, the following load combinations for displacement controlled and forced controlled is used.

Table 5. Force control load combinations

COMBF1- COMBF 4	1.1*(QD+QL) ± EX(ep) /(C1C2C3J) ± 0.3*EY/(C1C2C3J)
COMBF5- COMBF 8	1.1*(QD+QL) ± EX(en) /(C1C2C3J) ± 0.3*EY/(C1C2C3J)
COMBF9- COMBF 12	1.1*(QD+QL) ± EY(ep) /(C1C2C3J) ± 0.3*EX/(C1C2C3J)
COMBF13- COMBF 16	1.1*(QD+QL) ± EY(en) /(C1C2C3J) ± 0.3*EX/(C1C2C3J)
COMBF17- COMBF 20	0.9*(QD) ± EX(ep) /(C1C2C3J) ± 0.3*EY/(C1C2C3J)
COMBF21- COMBF 24	0.9*(QD) ± EX(en) /(C1C2C3J) ± 0.3*EY/(C1C2C3J)
COMBF25- COMBF 28	0.9*(QD) ± EY(ep) /(C1C2C3J) ± 0.3*EX/(C1C2C3J)
COMBF29- COMBF 32	0.9*(QD) ± EY(en) /(C1C2C3J) ± 0.3*EX/(C1C2C3J)

Table 6. Displacement control load combination

COMBD1- COMBD 4	1.1*(QD+QL) ± EX(ep) ± 0.3*EY
COMBD5- COMBD 8	1.1*(QD+QL) ± EX(en) ± 0.3*EY
COMBD9- COMBD 12	1.1*(QD+QL) ± EY(ep) ± 0.3*EX
COMBD13- COMBD 16	1.1*(QD+QL) ± EY(en) ± 0.3*EX
COMBD17- COMBD 20	0.9*(QD) ± EX(ep) ± 0.3*EY
COMBD21- COMBD 24	0.9*(QD) ± EX(en) ± 0.3*EY
COMBD25- COMBD 28	0.9*(QD) ± EY(ep) ± 0.3*EX
COMBD29- COMBD 32	0.9*(QD) ± EY(en) ± 0.3*EX

5.6. Force – capacity (DCR) ratio control

In the structure the linear dynamic analysis is used when demand capacity ratio (DCR) is less than 2. In order to find (DCR) for each element, the force in that element due to gravity and earthquake is determined, then the capacity of the element according to the expected ultimate strength is calculated and the ratio is found. The (DCR) ratio for elements is shown in Table 7. As this ratio is less than 2 for all elements, therefore the use of dynamic analysis is permissible.

Table 7. DCR ratio of elements for hazard level 1

Beam		Column			Shear Wall		
Shear	Moment	Axial Force	Shear	Moment	Axial Force	Shear	Moment
0.55	0.76	0.14	1.01	0.98	0.14	0.57	1.33

5.7. Acceptance criteria control

All controlled elements by deformation should satisfy following relation. In this relation m is the modified coefficient based on nonlinear behavior of the element, k is the coefficient which is depend on the specifications of the structure and is equal to one and Q_{CE} is the expected capacity of the element.

$$mkQ_{CE} > Q_{UD} \quad (5.7.1)$$

Also all controlled elements by forces in the structure should satisfy the following relation. In this relation Q_{CL} is the lowest bound member strength.

$$mkQ_{CL} > Q_{UF} \quad (5.7.2)$$

For selecting modeling parameters and for definition of different points on the diagram, plastic hinges in beams and columns according to the elements controlled by flexure and shear should be defined. In this process if the shear force capacity with the hinge plastic (with expected moments) at the end elements with gravity loads, that is obtained is higher than the shear capacity of the beam, the element should be controlled by shear and otherwise the element should be controlled by flexure.

For determining the parameter m, the existing table from Iranian retrofitting guidelines is used. The controls are in such a way that the ratio of force to the capacity is less than one. These controls for different elements are shown in Table 8.

Table 8. Relation controlled for elements acceptance

Moment acceptance in beams	(MUD)/(mkMCE) < 1
Shear acceptance in columns and beams	(VUF)/(kVCL) < 1
Moment acceptance in columns	$[(MUD_x)/(m_xkMCE_x)]2+[(MUD_y)/(m_ykMCE_y)]2 < 1$
Axial force acceptance in columns and walls	(PUF)/(kPCL) < 1
Moment acceptance in walls	(MUD)/(mkMCE) < 1

a) Acceptance criteria controls for beams: According to the calculation, it is found that the behavior of the beams is flexure. As beams are not surrounded by transverse reinforcement, the value of m for all beams is three. In this case the maximum values for beam acceptance in shear and flexure are 0.23 and 0.77. Therefore, as calculation shows, the acceptance criteria for all beams are accepted and beams are not needed to be retrofitted.

b) Acceptance criteria controls for columns: According to the calculation, it is found that the behavior of the columns is flexure. As columns are not surrounded by transverse reinforcement, the values for m_x and m_y for all columns are two. In this case the maximum values for column acceptance in shear, flexure and axial forces are 0.67, 0.63 and 0.013. Therefore as calculation shows, the acceptance criteria for all columns are accepted and columns are not needed to be retrofitted.

c) Acceptance criteria controls for walls: According to the calculation, it is found that the behavior of the walls is flexure. As walls are not surrounded by transverse reinforcement, the values for m_x and m_y for all walls are three. In this case the maximum values for wall acceptance in flexure and axial forces are 0.44 and 0.08. Therefore as calculation shows, the acceptance criteria for all walls are accepted and walls are not needed to be retrofitted.

6. EVALUATION AND ACCEPTANCE CRITERIA CONTROL IN HAZARD LEVEL 2

All step by step used in evaluation and acceptance criteria control in hazard level 1 will be used in this case. The results show that all acceptance criteria for columns, beams and shear walls are accepted.

7. SEISMIC EVALUATION AND RETROFITTING FOR FOUNDATION

In this section seismic vulnerability and retrofitting and also acceptance criteria for soil and foundation is studied. Software Safe2000 for modelling and analysis of the forces from structure on the foundation is used. Soil and foundation acceptance criteria for most critical hazard level i.e. hazard level 2 (CP) is controlled. Fig. 10 shows the foundation plan for central control building.

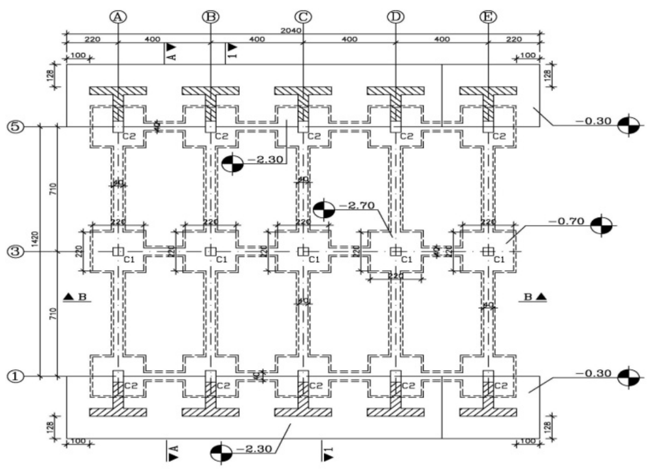

Figure 10. Central Control Building foundation plan

7.1. Acceptance criteria control for soil and foundation

Soil acceptance criteria: By using linear analysis the behavior of foundation should be controlled by deformation. Therefore the maximum stress in soil for all combination of deformation controlling loading and for hazard level 2, determine and will compare with the soil capacity. In linear analysis, the relation $Q_{UD}/KQ_{CE} < 3$ is used for foundation acceptance criteria. In the case we have:

$$Q_{UD}/KQ_{CE} < 10/3 = 3.33 \tag{7.1.1}$$

As all the great values of soil stress exist in the perimeter of wall and single existing foundation, therefore no excess stress will produce in the soil under foundation.
The results show that the stress under the soil is acceptable.

8. CONCLUSION

Central control building according to the Iranian retrofitting regulation instruction is studied. It is found that hazard level 1, its performance level is life safety (LS) and under hazard level 2 and its performance level is collapse prevention (CP). The studies shows that because of irregularities in torsion stiffness, liner static analysis is not permitted and linear dynamic analysis with specific site spectrum for seismic evaluation of the building should be used. The DCR control results shows that this ratio for all loading combinations which is controlled by deformation is less than two, and therefore the use of linear dynamic analysis for acceptance criteria control is permissible. The results obtained from acceptance criteria control for all beams, columns and shear walls shows that all elements satisfies the performance levels life safety (LS) and collapse prevention (CP), and therefore the building is not needed to be retrofitted.

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