Research Article

PROJECT OF THE STRENGTHENING OF A WATER TANK CARRIER SYSTEM WITH CARBON FIBER MATERIAL[1*]

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ABSTRACT

Elevated water tanks with reinforced concrete carrier systems are extremely important structures for public service or industrial use, and therefore they should be kept in a usable condition after an earthquake. The design and construction methods of these structures are affected by current construction practices, physical properties of the material and climatic conditions. Structural system damages are inevitable due to reasons such as improper designs, wrong analysis, lack of seismic wave resistant design, faulty geological preferences. In this study, the reinforced concrete carrier system of a sample water tank was examined in both cases, both in its current form and reinforced with FRP, using the SAP2000 program. By discussing the advantages of using FRP in these structures, it was suggested that it could be preferred primarily for reinforcement.

Keywords: *Pushover Analysis, Reinforcement, Seismic Performance, Vibration Forces, Elevated Water Tanks.*

1. INTRODUCTION

Elevated water tanks with reinforced concrete carrier systems are extremely important structures for public service or industrial use, and therefore they should be kept in a usable condition after an earthquake. The design and construction methods of these structures are affected by current construction practices, physical properties of the material and climatic conditions. Structural system damages are inevitable due to reasons such as improper designs, wrong analysis, lack of seismic wave resistant design, faulty geological preferences. Water tank design parameters include selecting the overall design of the tank, building materials and coatings. The design depends on the location of the tanks, different approaches are used for aboveground or underground water tanks [1]. Tanks can be made of RC or steel. Raised tanks are usually raised above ground level

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using columns and beams. Retrofitting is a method applied to increase the strength of the existing structure and also increases the strength of the newly constructed structures due to the error in the design and construction errors. If we list the methods of retrofitting. Over slabbing, sprayed concrete with additional reinforcement, steel plate bonding, external prestressing, concrete jacketing, steel jacketing and FRP wrapping [2,3].

2. MATERIALS AND METHODS

Housner conducted the first research to address the seismic response behavior of both underground and high water reservoirs exposed to earthquake lateral loads. Housner proposed a formulation to model the dynamic response of water inside tanks that are still widely used in engineering practice. According to Housner's proposed formulation, the hydrodynamic response is divided into two components of impulsive and convective vibration [4,5]. It is assumed that the impulsive vibration mode is attached to the tank wall (rigid connection). Convective motion, on the other hand, is the oscillation of the water surface, which has a longer vibration period, modeled as a collective mass attached to the wall using springs [6].

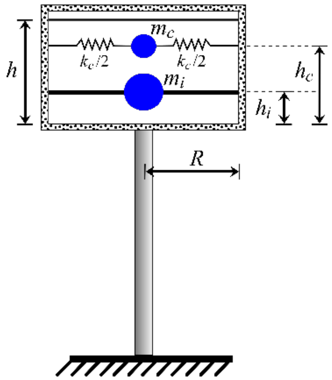


Figure 1: Mechanical model equivalent to the raised water tank

The equations for the Housner (Epstein, 1976) approximations for hydrodynamic pressure are set below [7].

$$\omega^2 = \frac{g}{R} 1.84 \tanh\left(1.84 \frac{h}{R}\right) \tag{1}$$

$$h_i = \frac{3}{8} h \tag{2}$$

$$k_c = m_c \frac{g}{R} 1.84 \tanh\left(1.84 \frac{h}{R}\right) \tag{3}$$

$$m_c = m_w \cdot 0.318 \frac{R}{h} \tanh\left(1.84 \frac{h}{R}\right) \tag{4}$$

$$m_i = m_w \frac{\tanh\left(1.74 \frac{R}{h}\right)}{1.74 \frac{R}{h}} \tag{5}$$

$$h_c = \left(1 - \frac{\cosh\left(1.84 \frac{h}{R}\right) - 1}{1.84 \frac{h}{R} \sinh\left(1.84 \frac{h}{R}\right)}\right) h \tag{6}$$

Where, w structural frequency, k_c stiffness of convective mass springs, m_c convective masses, m_i impulsive mass, h_c height of convective masses, h_i height of the impulsive mass, m_w total mass and g ground acceleration [8].

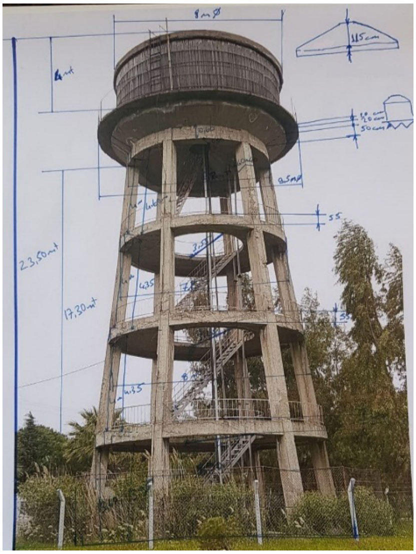


Figure 2: Sample water tank with RC carrier system

The SI international measurement unit system (kN, m) was used both in design, calculations and drawings.

Table 1: SI international units of measure

Physical size	Unit of
Length	m
Loads	kN
Weight	kN
Mass	Kn.sn^2/m
Momentum	kN.m
Stress	kN/m^2

For the structural design of the structure, SAP2000 Ver 14.2.4 computer aided design and analysis program, capable of performing finite element analysis, was used. The dead load will include the weights of all fixed parts of the structures and their additions. The following assumptions have been made for all weight calculations.

- Roof cover volume unit weight, $\gamma = 0.25$ kN/m^2
- Volume unit weight of reinforced concrete, $\gamma = 25.0$ kN/m^3
- Volume unit weight of concrete without reinforcement, $\gamma = 25.0$ kN/m^3
- G dead = dead load
- WG = water weight
- Q live = 3 kN/m^2

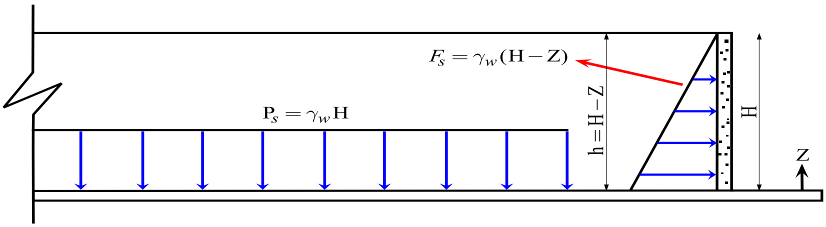


Figure 3: Hydrostatic pressure (a)

If we take $F_s = \gamma_w (H - Z) = 1000(4 - Z)$ and $Z = 0$

$F_s = 4000$ kg/m^2 = 40 kN/m^2 is found.

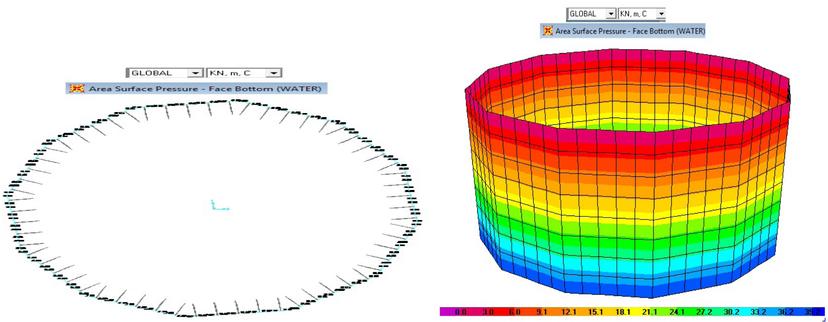


Figure 4: Hydrostatic pressure (b)

Table 2: Effective ground acceleration coefficient (A_0)

Earthquake Zone	A_0
1	0.40
2	0.30
3	0.20
4	0.10

The effective ground acceleration coefficient for the earthquake load is taken as A_o = 0.4, building importance factor, I = 1 and soil group = C (Soil Investigation Report). The Spectrum coefficient is calculated from the following equations.

$$S(T) = \begin{cases} 1+1.5\dfrac{T}{T_A} & , 0 \le T \le T_A \\ 2.5 & , T_A < T \le T_B \\ 2.5\left(\dfrac{T_B}{T}\right)^{0.8} & , T_B < T \end{cases} \tag{7}$$

The following defined reduced acceleration spectrum is used in Sap2000.

$$S_R(T_n) = \frac{S(T_n)}{R_a(T_n)} \tag{8}$$

Calculation of the storey masses was made by taking n = 0.3 according to the following equations.

$$W = \sum_{i=1}^{N} w_i \tag{9}$$

$$w_i = g_i + nq_i \tag{10}$$

Table 3: Spectrum characteristic periods (T_A, T_B)

Local ground class	T_A (sec)	T_B (sec)
Z1	0.10	0.30
Z2	0.15	0.40
Z3	0.15	0.60
Z4	0.20	0.90

For the internal forces found, the section will be increased by taking β = 0.9, and if $V_{tB} < \beta.V_t$ for the predicted earthquake, all internal force and displacement magnitudes found according to the mode combination method will be increased according to equation 11.

$$B_D = \frac{â V_t}{V_{tB}} B_B \tag{11}$$

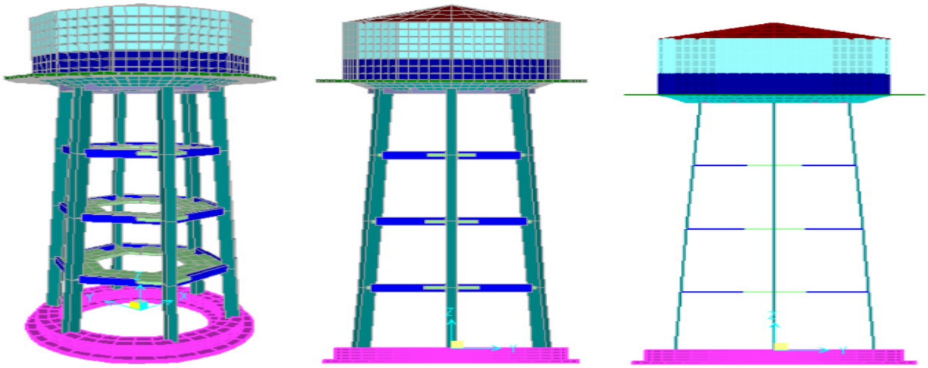


Figure 5: Computer model of the building

Where V_{tB} is the building total load and V_t is the building total earthquake load. The formulas used for the equivalent earthquake load value to be used for the above calculation;

$$A(T) = A_0 \cdot I \cdot S(T) \tag{12}$$

$$S_{ae}(T) = A(T) \cdot g \tag{13}$$

$$V_t = \frac{W \cdot A(T_1)}{R_a(T_1)} \geq 0.10 \cdot A_0 \cdot I \cdot W \tag{14}$$

$$T_1 = 2\pi \left(\frac{\sum_{i=1}^{N} m_i \cdot d_{fi}^2}{\sum_{i=1}^{N} F_{fi} \cdot d_{fi}} \right)^{\frac{1}{2}} \tag{15}$$

Input Parameters		
Fluid Unit Weight, γ =	1	ton/m^3
Tank Diameter, R =	4	m
Water Height, h=	4	m
Seismic Zone=	1	
Soil Type=	Z3	
Important factor, I=	1	
TA=	0.15	sec
TB=	0.6	sec
Reduction Factor, R=	4	
Effective Ground Acceleration, A0=	0.4	g
Natural Period of Vibration of the Fluid Tank, T =	3.033353	sec
Spectral Acceleration, SA	0.068379	g
Acceleration Gravity	9.81	m/s^2
General Computations		
Water Weight, W=	230	ton
Steel Tank Weight, Wt =	185	
Calculations of Impulsive Forces		
Equivalent weight of fluid, W0=	124.7299	ton
Gross Equiavelent weight of fluid, W0''=	309.7299	ton
Application distance from the bottom of the tank, h0 (EBP) = h0''=	1.5	m
Application distance from the bottom of the tank, h0 (IBP) =h0''=	3.187969	m
Impulsive Force, P0=	49.89195	m
Modified Impulsive Force, P0'' =	123.892	ton
Bending Moment, M0'' (EBP)=	185.8379	ton.m
Bending Moment, M0'' (IBP)=	394.9638	ton.m
Calculations of Convective Forces		
Equivalent Oscillating Weight, W1=	69.54116	ton
Application distance from the bottom of the tank, h1 (EBP)=	2.421962	m
Application distance from the bottom of the tank, h1 (IBP)=	3.137424	m
Circular frequency of free Vibration, ω =	2.071366	rad
Natural Period of Vibration, T =	3.033353	sec
Maximum Displacement of W1, A1=	0.323843	m
Angular amplitude of water free oscillation, θh =	0.118083	
Convective Force, P1=	9.853947	ton
Bending Moment, M1 (EBP)=	23.86589	ton.m
Bending Moment, M1 (IBP)=	30.91601	ton.m
Maximum Water surface Displacement, dmax=	0.446913	m
K rigidity of the mass of oscillation	298.0662	ton.m

Figure 6: Hydrodynamic forces in a cylindrical tank (h <1.5R)

3. REINFORCEMENT OF THE WATER TANK USING FRP

The displacement limit for the non-reinforced model is =: (disp/h) < 0.025, disp (max) = 0.025x18.35x100 / 4.5 = 10.1 cm and the displacement in the model is = 17.80 cm. If we take the time period = 1.26;

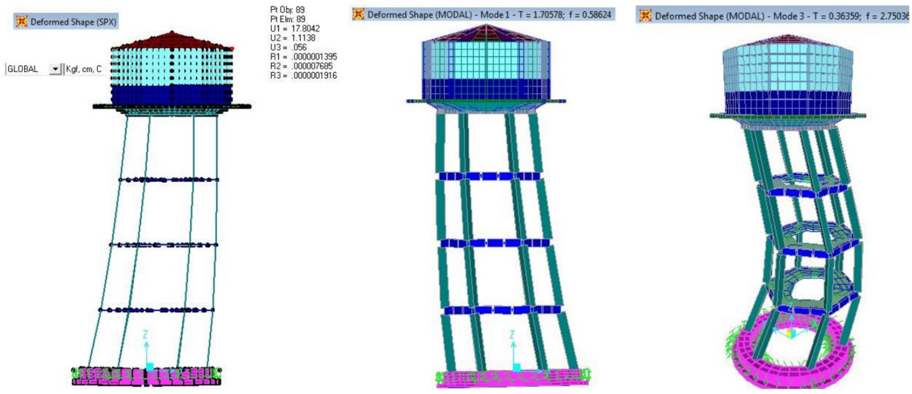
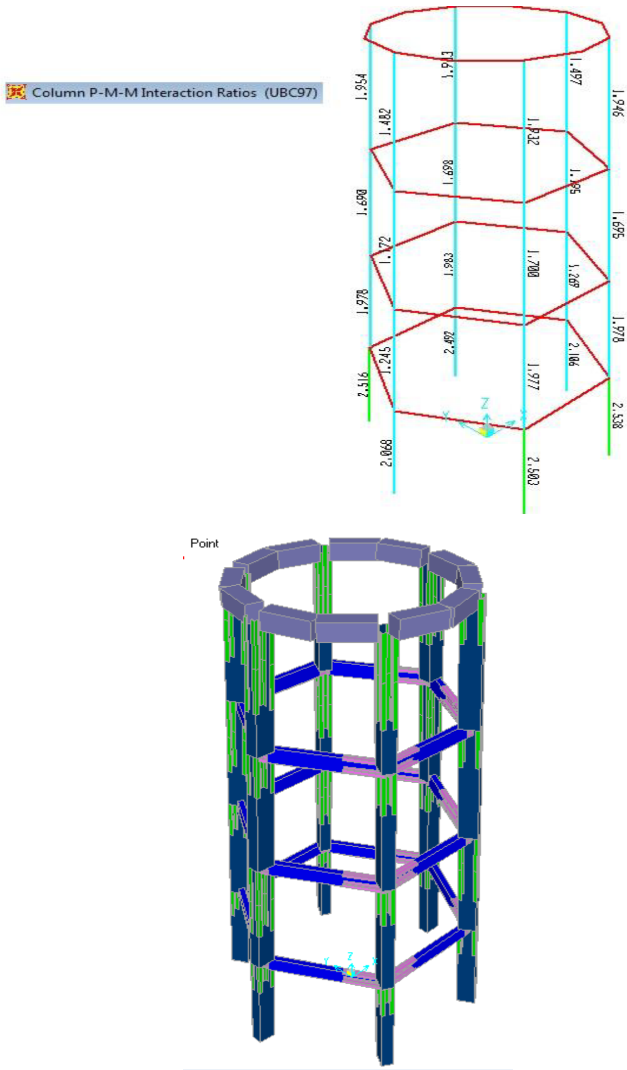


Figure 7: Deformed shape

All of the columns have 2Ø14 iron in 4Ø22 cores on short corners and stirrups are positioned Ø8/20 cm apart. For all the beams, there are 2Ø12 piles at the top and 4Ø12 reinforcement at the bottom. In this model, the concrete class has been entered as f_c = 10 Mpa.



(a) (b)

Figure 8: (a) Column and beam design (not reinforced) (b) Bracing made in beams and columns

For the model reinforced with FRP, the braces are 4 pieces (12x12x1) and the brace area is: 24x4 = 96 cm^2.

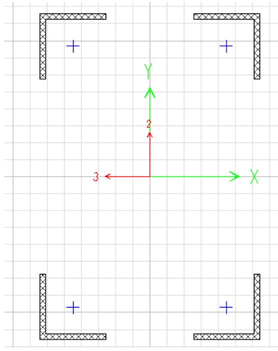
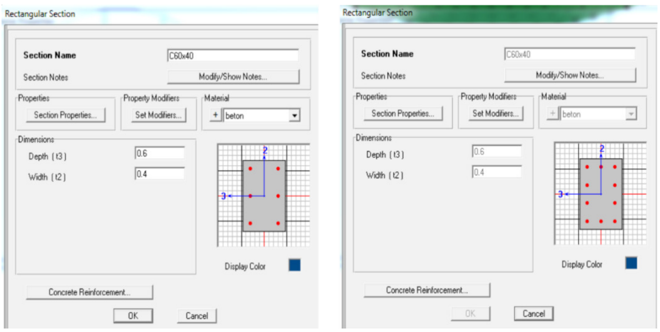


Figure 9: Column section with FRP bracing

After these brackets are made, we use the section in Figure 10 (b) instead of the column section.



(a) (b)

Figure 10: (a) Non-reinforced column section (b) Reinforced column section

Assuming that it increases the axial strength of the column by 100 %, the concrete class has been entered as f_c = 20 Mpa.

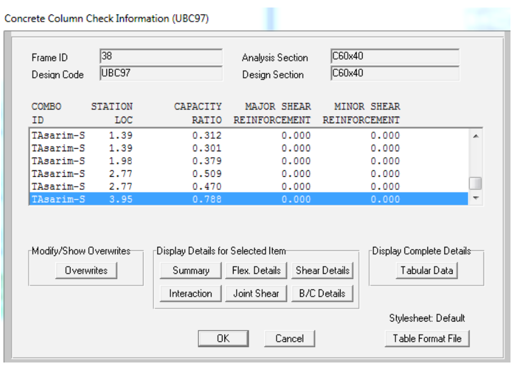


Figure 11: Column check information

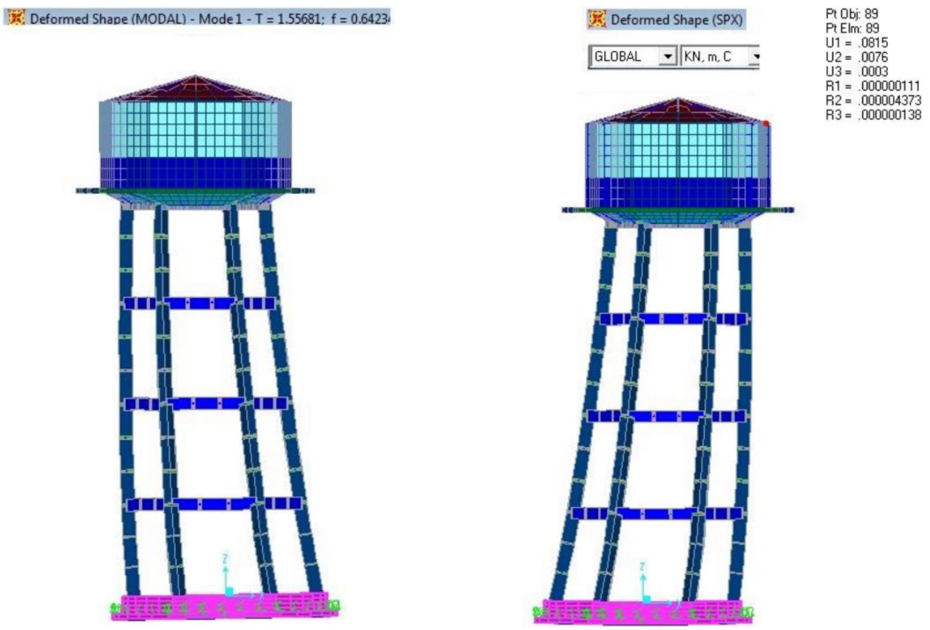


Figure 12: Time period = 1.56 seconds (period dropped 20%)

The displacement limit =: (disp/h) x cd < 0.025 and disp (max) = 0.025 x 18.35 x 100 / 4.5 = 10.2 cm > 8.2 cm.

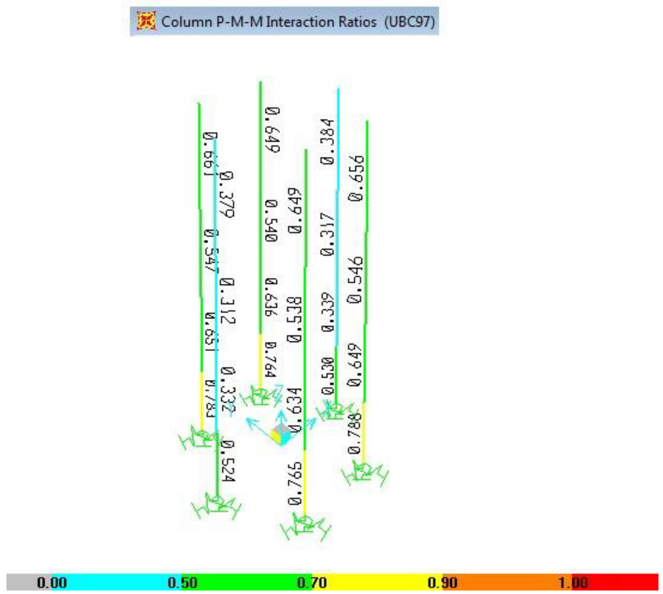


Figure 13: Column P-M-M interaction ratios

k_s = 10000 kN/m^3 and ground safety tension = 100 kN/m^2.

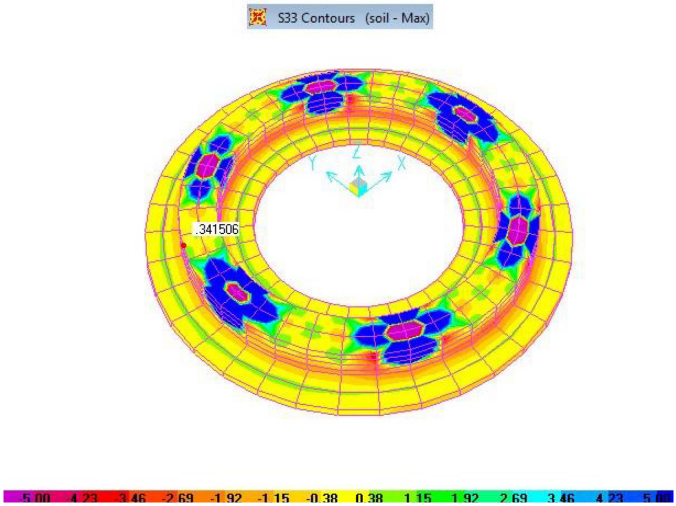


Figure 14: Foundation stresses (0.75 Dead + 0.75 Q Live + 0.75 SPX) were taken.

4. CONCLUSION AND SUGGESTIONS

FRP has an elastic behavior up to failure, unlike steel which exerts a constant wrapping pressure after application, and therefore applies the wrapping action differently than steel on concrete specimens under axial load. The advantages of using FRP to strengthen the carrier systems of water tanks can be listed as follows.

- It is resistant to corrosion,
- High strength / weight ratio,
- Shorter assembly time and cost,
- It is not conductive and metallic,
- Low maintenance requirements,

Fire resistance, which is an important disadvantage in the use of FRP, is not valid in water tanks. The possibility of fire in a building with risks from heating systems or full of flammable materials is not present in the water tank. In addition, we can talk about an extra advantage since no flammable material is stored in this type of tank. The possibility of leaks in the water tanks to cause corrosion in the conveyor system due to wear or insufficient maintenance is seriously reduced by the use of FRP. Advantages of using FRP over steel reinforcement include linear elastic behavior on failure, no yield, higher ultimate strength, and lower strain on failure. As a result, the use of FRP in water tanks is extremely important due to its increased load capacity and increased deformation capability.

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