Wind Design Loads on Large Billboard Based on Iraqi and ASCE7Standards

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***Abstract**:In Iraq billboards structures are installed without engineering design therefore, billboards and signs are commonly failed during strong winds, thus engineering design of these structures is necessary from cost and functionality points of view especially for large billboard. This study presented a detailed procedure to determine the design wind loadings on large billboard in Iraq according to two codes, i.e., ASCE7-05 and Iraqi Code IQS301. For each code all factors are presented to correspond the Iraqi topography and environment conditions. The basic wind speed for design purposes is specified according to Iraqi standards IQS301. A numerical comparison between codes is presented based on the different wind loadings namely,Maximum horizontal wind pressure, Maximum total horizontal force, Maximum bending moment, Maximum torsion, the different in wind loadings between codes is presented. It found that ASCE7-05 code more accurate and yields higher wind loads than Iraqi code. It's found that Iraqi code IQS301 yields wind loads less than ASCE7-05 with percent of 78.5%. Also,it's found that Iraqi Code IQS301 in the present edition is not suitable for determine the design wind loads on billboard structures and other flexible structures or structures sensitive to the dynamic wind effects.*

***Keywords**: Solid signs, billboards, wind loadings, Iraq, IQS301, ASCE7-05*

I. Introduction

The signs are widely used in Iraq as in all world regions, in which these signs mainly used as billboards for economical and markets purposes as a tool of advertisement in additional to another tools of advertisement like satellite channels, radio, internet, newspapers and so on. But in additional to economical advertisement, signs also commonly used by governments as attentions for dangerous places or to avoid unsafe behavior in some locations like these used for traffic purposes.In Iraq the using of these signs still limited on relatively small dimensions solid signs located in urban and markets areas, in which for these cases the effect of wind on signs are relatively not critical. Nowadays there is a tendency of both private sector and investors and also governmental organizations to use large signs in urban and open areas for their own business like on main roads. For these large signs wind loads play the main role in their design. In Iraq commonly theses type of structures is installed with local labor or skills without engineering design take into account design load and especially wind forces therefore, billboard and sign in Iraq commonly failed during high wind speed or storm conditions.

In general, there are few studies regards billboard structures and effect of winds on. Estrada and Chiu[1] developed a Microsoft visual basic computer program for the analysis of wind loads on buildings and signs. The material used to develop this program was derived mainly from ASCE 7 specifications. It can be used to compute

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the wind pressures that act on signs and buildings.Barle et al. [2] presented failure analysis of the highway sign supporting structure due to wind loading. Nagyov et al. [3] found that the geometric non-linear theory of large deflections must be used for a description of behavior of thin steel plate. Zuo et al. [4] conducted wind-tunnel tests to study wind loading on elevated rectangular sign structures of various configurations. They concluded that the configuration of the rectangular sign faces significantly affects the loading on these structures and the torque acting on rectangular sign structures is overestimated by a standard and code.Zu [5] carriedout the Canada code CHBDC calibration analyses of the sign, luminaire and traffic signal support under natural and truck-induced wind gusts. Ganiron Jr [6]proposed a structural analysis and design of latticed billboard structures and closed signage structures according to modified version of National Structural Code of the Philippines (NSCP).Wang et al. [7] presented a wind tunnel study of wind loads of the large billboard structures with two-plate and three-plate configurations. They concluded thatthe wind load characteristics of windward plate in both two- and three-plate configurations are very similar.

This paper present detailed steps to evaluate the wind loadings on tall solid sign in Iraq environment, and specify the critical actions of wind on sign and the necessary quantities needed by designers according to two codes which are ASCE7-05 [8], and Iraqi Code IQS301 [9]. Thus, this study will be useful tools for both private and governmental sectors that may plan to install large billboard solid signs in Iraq.

II. Description of Large Billboard

Large billboards configurations either single plate configuration, or two-plate and three-plates configurations as shown in Fig. 1. Large billboard structure in Iraq with less than 20m high above the ground (commonly 12m above ground, width 14m and height 4m), but typically these structures may be 20 to 50 m high above the ground and with large rectangular plates about 20 to 30 m in width and 5 to 8 m in height [7]. The billboards are supported by enclosed truss or frames which are then supported by a mono-pole. These large billboards subjected to damages or in some cases to failures due to strong winds. These damages and failures can be local damage of the connection bolts between the cladding plate and supporting structure, damage of the plate skin due to the intensive local wind pressures on the plate, damage of plate supporting frame, bucking of the supporting column, and failure of its foundation bolt connection [7].

a- Single Plate

b- Double Plate

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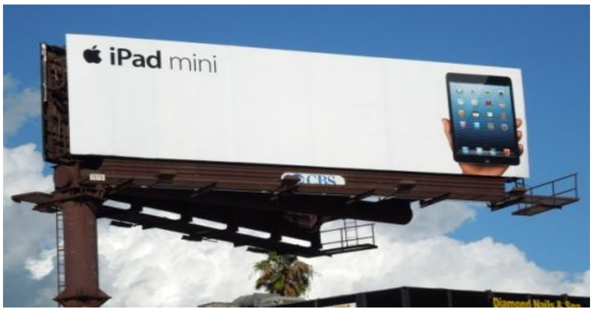

c- Double Plate V-shaped

d- Three plates

Figure 1. Large billboards configurations.

III. Basic Wind Speed (V)

In all codes wind speed is used to calculate the loadings of wind on structures. For design purposes there are contour maps for each country accomplished by meteorologists and climatologists to find this basic wind speed. The basic wind speeds in Iraq is determined from zoning map presented by Iraqi specifications IQ 301 [9], which is corresponds to the 3 second-gust speed at 10 m above ground in open terrain as shown in Fig. 2.

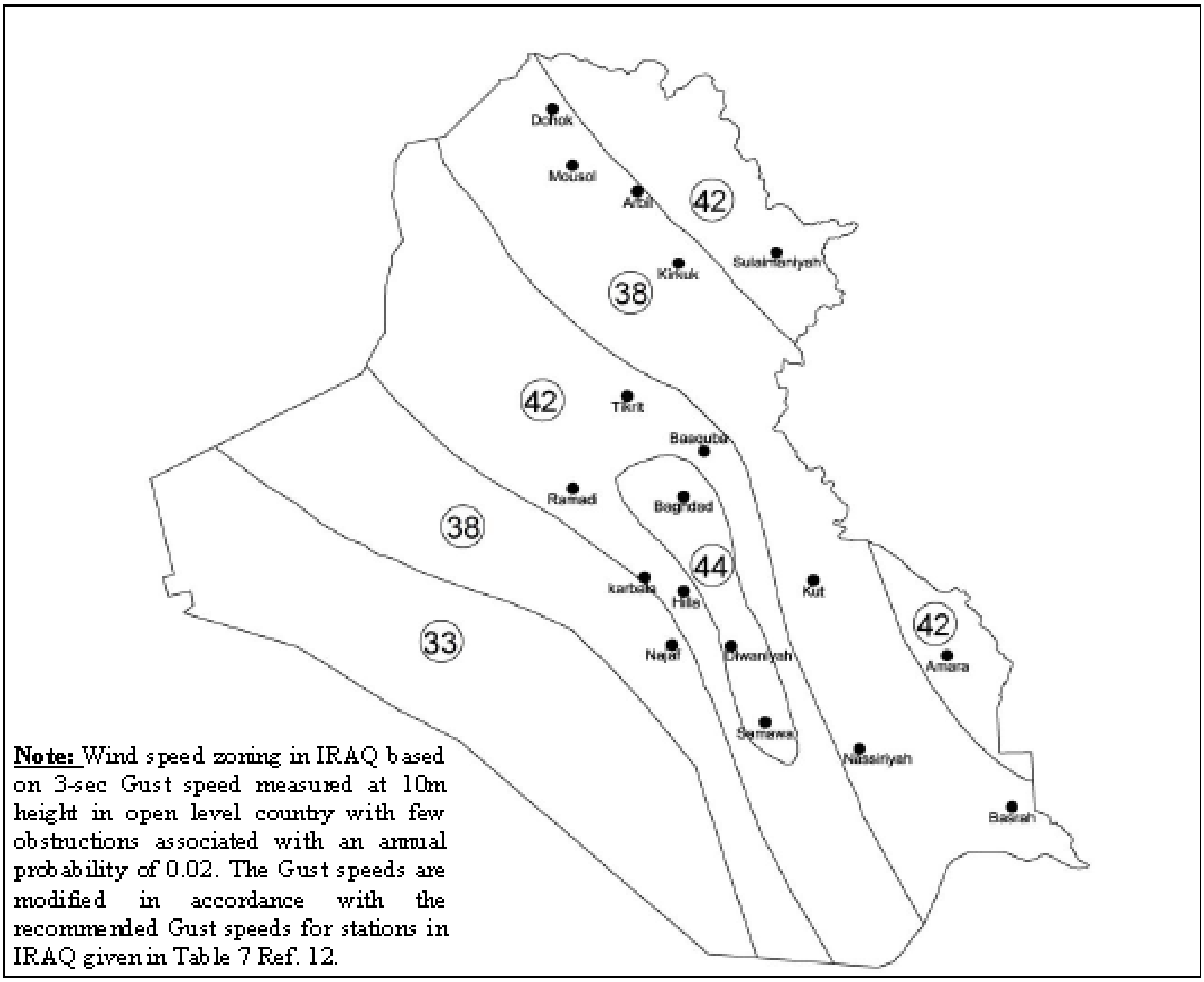

Figure 2. Contour map for basic wind speeds of Iraq.

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ASCE7-05 [8], presents three approaches to determine the design wind loads on different buildings or structures. Choice of any one from above methods is depend on the structure properties and surround environment characteristics. Analytical approach (method 2) is suitable to determine the design wind loadings on tall solid signs in Iraq conditions. The velocity pressure at any height z is calculated by the following equation (ASCE7-05):

$$q_z = 0.613 K_z K_{zt} K_d V^2 I \qquad (N/m^2) \qquad (1)$$

Where

V=basic wind speed, m/sec

$K_d =$ Wind Directionality Factor=0.85 for solid signs (Table 6-4 of ASCE7-05)

$K_{zt} =$ Topographic Factor = 1.0 for south of Iraq (flat terrain areas) (Fig 6-4 of ASCE7-05).

$K_z =$ Velocity Pressure Factor

$I =$ Importance Factor =1.0 for solid sign southern Iraq (Table 6-1 of ASCE7-05).

Velocity Pressure Factor k_z is determined from Table 6.3 of ASCE7-05.The dynamic effects of wind are accounted in the equation of design wind pressure through apply the gust factor G. To determine gust factor, it should specify whether the structure is rigid or flexible. ASCE7-05, define the rigid and flexible structures as follow:

- Rigid Structure: A structure that has fundamental frequency equal or greater than 1 Hz.
- Flexible Structure: A structure that has fundamental frequency less than 1 Hz.

In general, the tall signs and according to their structural characteristics are considered as flexible structures in which dynamic behavior is important. Thus, gust factor G is determined as follow:

$$G = 0.925 \left(\frac{1 + 1.7\, I_{\overline{z}} \sqrt{g_Q^2\; Q^2 + g_R^2\; R^2}}{1 + 1.7\, g_V\, I_{\overline{z}}} \right) \qquad (2)$$

$$g_Q = g_V = 3.4 \qquad (3)$$

$$I_{\overline{z}} = c \left(\frac{10}{\overline{z}} \right)^{1/6} \qquad (4)$$

$\overline{z}$ is the equivalent height of the structure, for signs it should be the height to the middle of sign as shown in Fig. 3, and should satisfy $\overline{z} \geq z_{min}$,where c and z_{min} are constants determined from Table 6-2 of ASCE7-0.

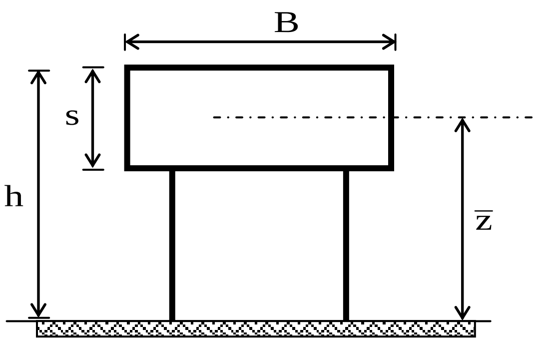

Figure 3. The equivalent height of the sign.

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$$g_R = \sqrt{2\ ln(3{,}600\, n_1)} + \frac{0.577}{\sqrt{2\ ln(3{,}600\, n_1\ )}} \qquad (5)$$

n_1 is the structure (sign) natural frequency

$$Q = \sqrt{\frac{1}{1+0.63\left(\frac{B+h}{L_{\overline{z}}}\right)^{0.63}}} \qquad (6)$$

B is the horizontal dimension of the sign and h is the height of sign

$$L_{\overline{z}} = \ell\, (\frac{\overline{z}}{10})^{\overline{\varepsilon}} \qquad (7)$$

$$R = \sqrt{\frac{1}{\beta} R_n\, R_h\, R_B\, (0.53 + 0.47\, R_L)} \qquad (8)$$

$$R_n = \frac{7.47\, N_1}{(1+10.3\, N_1)^{5/3}} \qquad (9)$$

$$N_1 = \frac{n_1\, L_{\overline{z}}}{\overline{V}_{\overline{z}}} \qquad (10)$$

$$R_i = \frac{1}{\eta} - \frac{1}{2\eta^2}(1 - e^{-2\eta}) \quad \text{for } \eta > 0 \qquad (11)$$

$$R_{i=} 1 \text{ for} \qquad \eta = 0 \qquad (12)$$

$$R_h = R_i \text{with} \eta = 4.6\, n_1\ h/\overline{V}_{\overline{Z}} \qquad (13)$$

$$R_B = R_i \qquad \text{with } \eta = 4.6\, n_1\ B/\overline{V}_{\overline{Z}} \qquad (14)$$

$$R_L = R_i \qquad \text{with } \eta = 15.4\, n_1\ L/\overline{V}_{\overline{Z}} \qquad (15)$$

β is the damping ration as percent of critical (for sign β values between 1%-2% may be used) and $\overline{V}_{\overline{z}}$ = mean hourly wind speed at height $\overline{z}$ and equal to:

$$\overline{V}_{\overline{Z}} = \overline{b} \left(\frac{\overline{z}}{10}\right)^{\overline{\alpha}} V \qquad (16)$$

Where $\overline{b}$, c, z_{min}, ℓ, $\overline{\alpha}$ and $\overline{\varepsilon}$ are constant obtained from Table 6-2 of ASCE7-05,and V is basic wind speed.The design wind pressure on solid signs is determined by the following equation, ASCE7-05:

$$P = q_h G\ C_f\ N/m^2 \qquad (17)$$

Where, q_h velocity pressure evaluated at z = h, G = gust-effect factor, and C_f = net force coefficient determined from Fig. 6-20 of ASCE7-05. The design force of wind on solid signs are calculated by $F = p * A$, where A is the gross area of the sign (A = B × s).

Desıgn Loadıngs of Wınd Actıons on Tall Soıld Sıgns. The design of signs (its foundations and superstructure) should take into account safe resistance to internal forces that sign may be faced due to gravity and wind loads. For signs subjected to wind effects, there are four quantities or loadings that govern the design of sign frame and its foundation, these quantities are:

- Maximum horizontal wind pressure.
- Maximum total horizontal force.
- Maximum bending moment at the base level (pole support).
- Maximum torsion.

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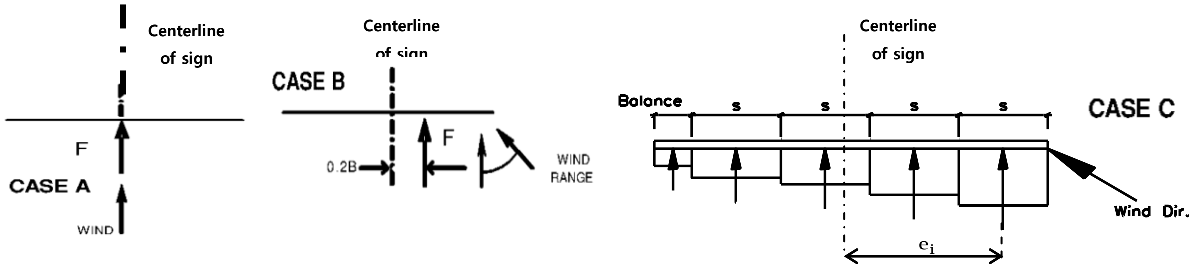
To find these critical loads, ASCE7-05 requires that any sign should be designed for the three wind cases that defined in Fig. 4, and the most critical case must be consider in the design. These cases are:



CASE A CASE B CASE C

Figure 4.ASCE7-05 wind load cases on solid signs.

CASE A: Resultant Forces Through The Geometric Center of Sign. If the resultants of wind forces pass through the center of sign, then there are no torsional effects, and the design forces calculated as follow:

Horizontal wind pressure = $P = q_h \times G \times C_f$ (18)

Total Horizontalwind Force = $F = P * A$ Where $A = B \times s$ (19)

Bending moment = $M = F \times (h \_ 0.5 \times s)$ (20)

Torsion = T = 0 (due to no eccentricity) (21)

CASE B: Resultant Forces at 0.2B Offset of The Geometric Center of Sign. If the resultant of wind forces has eccentricity with the center of sign, then there will be torsional effects, and the design forces are similar to CASE A except that:

$T = F * 0.2\, B$ (22)

CASE C: Resultant Forces Through The Geometric Centers of Each Region. This case must be considered if $\frac{B}{s} \geq 2$ which is commonly valid for signs. In this case the width of sign B is divided into small regions or portions each region have width equal to s (sign vertical dimension) as in Fig. 5.

$P_i = q_h * G * C_{fi}$ (23)

Where C_f is determined from figure 6-20 of CASE C

$F = \sum F_i$, $F_i = P_i * A_i$ where A_i =area of each region (24)

$M = \sum M_i$ and $M_i = F_i * (h - 0.5 * s)$ (25)

$T = \sum T_i$ and $T_i = F_i * e_i$ (26)

e_i : eccentricity of the center of each region from the center of sign

Wind Loadings on Large Billboards According to IQS 301 Iraqi Code

The Iraqi code for wind forces not gives any explicit attention to solid signs and also not takes into account the dynamic action of wind as in ASCE or India codes that incorporate dynamic action via gust factor. The design wind speed V_s is obtained from the following formula:

$V_s = V\, S_1 S_2 S_3$ (27)

Where V= basic wind speed in m/s, S_1= topography factor, for middle and southern of Iraq (flat terrain) this

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factor equal one, S_1=1.0, S_2= Ground Roughness, structure Size and height above Ground factorcalculated from (Table (2.3/1) of IQS301), and S_3= Statistical factor, for wind speed with 50 year mean recurrence interval on building and structures (not in construction stages) this factor equals unity, Thus for southern Iraq conditions, S_3=1.0. The design wind pressure at height z:

$$q = 0.613\, V_s^2 \quad (N/m) \tag{28}$$

Iraqi code presents a simplified method to find total wind loads on a structure which is suitable for tall solid signs and it is given by:

$$F = C_f\, q\, A_e \tag{29}$$

Where F= along wind load on the structure, A_e= effective frontal area, C_f= force coefficient for the building. There is no value of force coefficient for signs in Iraqi code, but it can be estimated from Table2.3.6 of Iraqi code to be equals 1.3 (C_f=1.3) dueto most tall solid sign has:

- $\frac{b}{d} \geq 4$ or $\frac{L}{w} \geq 4$, where b the dimension of structure normal to wind and d the dimension parallel to wind, L larger horizontal dimension n and w smaller horizontal dimension, in Signs notations b and L represent sign width (B) and d and w is the sign thickness .
- $\frac{1}{2} < \frac{h}{b} \leq 4$, where h is the height above ground.

IV. Numerical Analysis

A tall billboard solid sign are to be installed in Baghdad on the expressway (Route No. 6), have the following data:Terrain: Flat and open terrain, therefore use exposure C.Building Classification: Failure of sign represents low hazards to human life since it is located away from highway and is not in populated area, thus the structure can be classified as category I.Dimensions: 20 m × 6 m billboard and mounted steel truss supports, bottom of the sign is 10 m above the ground. The thickness of billboard is 1 m.Structural characteristics: Tall flexible structure, estimated fundamental frequency 0.7 Hz [10] and critical damping ratio is 0.016. Basic wind Speed: For Baghdad area basic wind speed is 44 m/s.For the sake of comparison of wind loading computed according different codes the wind load is estimated by ASCE7 procedure and also by Iraqi code IQS 301. The design parameters, factors, design wind pressure and horizontal; force for each code are summarized in Table 1. Due to Iraqi Code IQS301 not included explicit consideration for signs, the bending moment and torsional forces for IQS301 is obtained according to procedure given by ASCE7-05, Case B, namely:

$$\text{Bendingmomnet} = \text{M} = \text{F} * (\text{h} - 0.5 * \text{s})\text{and}\text{T} = \text{F} * 0.2\text{B}$$

Where B= billboard width, h= elevation from ground and s = billboard height.

Table 1. The design parameters, factors, design wind pressure and horizontal force on Billboard in Baghdad.

ASCE7-05	IQS301 (Iraqi Code)	ASCE7-05
Exposure C	Category 2	$\ell = 152.4\text{m}$
Building Category II	V=44 m/s, Fig. 2	$\bar{\varepsilon} = 1/5$
V=44 m/s, Fig. 2	S_1=1.0	$b = 0.65$

I=1.0	S_2= 0.944	$\bar{\alpha} = 1/6.5$
$K_{zt} = 1.0$	S_3=1.0	$\beta = 0.016$, assumed
$K_d = 0.85$	V_s=41.54 m/s, Eq. (32)	S= 6m
$K_z = K_h = 1.1$,	$q = \rightleftarrows 1057.78 N/m^2$, Eq. (33)	G=1.034, Eq. (2)
$q_h = 965.4 N/m^2$, Eq. (1)	C_f = 1.3	$p = 998.2 \ C_f$, Eq. (17)
$\bar{z} = 13, m$	F = 165KN, Eq. (34)	$C_f = 1.76$ (CASE A)
$n_1 = 0.7 Hz$, given	-	$p = 1.757 \ kN/m^2$
$z_{min} = 4.57, m$,	-	F = 210.84 kN
c = 0.2, Table 2	-	-

The three scenarios of ASCE7 specifications are considered in the present study, where Case A yielded highest horizontal force and bending moment of 210.84 kN and 2740.92 kN.m respectively, while Case B yielded highest torsional moment of843.36 kN.m. The horizontal wind force and other design quantities for ASCE7-05 Case C scenario is presented in Table 2.

Table 2. Horizontal wind force and other design quantities for ASCE7-05 Case C scenario.

Distance, m		$\mathbf{C_f}$	$\mathbf{p_i, kN/m^2}$	$\mathbf{A_i, m^2}$	$\mathbf{F_i, kN}$	$\mathbf{M_i, kN.m}$	e_i , m	$\mathbf{T_i, kN.m}$
0 to s	6	2.7	2.7	36	97.2	1263.6	7	680.4
S to 2s	12	1.77	1.77	36	63.72	828.36	1	63.72
2s to 3s	18	1.2	1.2	36	43.2	561.6	-5	-216
3s to 10 s								
$\sum$					204.12	2653.56		528.12

From Table 1, the design horizontal pressure on billboard of ASCE7and IQ301 codes is, 1.757kN/$m^2$and 1.38kN/m^2 $(q*C_f)$ for ASCE7-05 and IQ301 respectively, and the maximum total horizontal force of each code is, 210.84 kN and 165kN for ASCE7-05 and IQ301 respectively. Thus IQS 301 yielded design wind pressure and horizontal wind force of 78.5% from that obtained according to ASCE7 procedure. The comparison between IQS301 and ASCE7 based on different design quantities is presented in Table 3.

Table 3. Wind design loads for different codes.

Load Type	**ASCE7-05**			**IQS301**
	CASE A	**CASE B**	**CASE C**	
Design horizontal pressure, kN/m^2	1.757	1.757		1.38
Max. total horizontal force (F), kN	210.84	210.84	204.12	165
Max. bending moment (M), kN.m	2740.92	2740.92	2653.56	2145
Max. torsion (T), kN.m	0	843.36	528.12	660

According to Table 3, the maximum bending moment at at the base level (pole support) of each code is, 2740.92kN.m and 2145kN.m for ASCE7-05 and IQ301 respectively, while the maximum torsion of each code is, 843.92kN.m and 660kN.m for ASCE7-05 and IQ301 respectively. Due to all above quantities differ based on the design horizontal pressure, thus discussion is limited to design wind pressure which is applicable to other quantities exactly. ASCE7-05 yields higher pressure than IQS301 due to in ASCE7-05 specification take into account the solid sign structures and all coefficient are for this type of structure which is flexible and dynamic sensitive structure so ASCE7-05 is the more accurate specification than other three codes in deals with solid sign and billboard and it is considered as reference of the comparison in the present study, Iraq Code IQ 301 yields the lower value for pressure 78.5% of ASCE7-05 pressure due to the this code not take into account the wind effects on billboard and signs and there are no special attention for signs in the parameters or tables of this code, also the present draft version of IQ301 not deals with flexible structure that sensitive to dynamic action of winds which commonly incorporated in international codes via gust factor.

It should be noted that for flexible building structures although most codes determine the wind using gust factor method and each code gives specified coefficients and factor for these building but still there are differences in estimation of wind forces on the same building with the same characteristics.Zhou et al. [11], presented a comprehensive assessment of the source of the scatter exists among the wind effects predicted by the various codes and standards under similar flow conditions, through a comparison of the along-wind loads and their effects on tall buildings recommended by major international. They noted that the scatter in the predicted wind loads and their effects arises primarily from the variations in the definition of wind field characteristics in the respective codes and standards.

V. Conclusions

From the present study the following conclusions can be drawn:

- ASCE7-05 more accurate than IQ301 codes to determine the wind loads on billboards structures in Iraq and yields higher wind loads than IQS301 due to ASCE7-05 specification take into account the solid sign structures and specified special factors and parameters for this type of structures. Thus ASCE7-05 code is recommended to determine the wind loads on large billboards structures.
- Iraqi Code IQ301 yields the lower value for wind loads than ASCE7-05 -05 by about 78.5%, thus Iraqi Code IQS301 in the present edition is not suitable for determine the design wind loads on billboard structures and other flexible structures or structures sensitive to the dynamic wind effects.
- The design or analysis of large billboards should be preceded by free-vibration analysis to find the fundamental natural frequency that has important effects on wind load calculations.

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