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Comparison of Wind Load among Bangladesh National Building Code (BNBC) and Other International Codes

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Abstract: - The structures, or Bridges and Buildings, as well as their components, must be built to withstand the prescribed wind loads. Wind load-resisting structures, including structural components, components, and cladding, must be designed to withstand shearing, sliding, overturning, and uplifting forces as a result of wind forces. Because wind loads are a component of rational loads, following a standard and tested building code can be used to provide this function. The Bangladesh National Building Code (BNBC) and the Japan Road Association (JRA) were issued in 1993 and 1947, respectively, to fulfill this purpose in Bangladesh and Japan, respectively. Because of the way lateral loads are applied and handled in various codes, the antedated 1993 BNBC is replaced by a subsequent BNBC code that is commonly named the BNBC 2020, which was issued in Bangladesh in 2021. In this paper, the BNBC codes are studied and compared with each other and with JRA 2012, AASHTO 2012, AASHTO 2020, and ASCE 7-05. The investigation reveals that the percentages of the basic wind speed increase according to BNBC 1993 and BNBC 2020 significantly increased compared to the recent codes, but the investigation also reveals that the designed wind pressure in different exposures is slightly higher according to BNBC 1993 than BNBC 2020. Design wind pressure and applied wind load according to BNBC 2020 is equal to or higher than ASCE 7-05. Designed wind pressure is comparatively less and slightly higher for BNBC 2020 compared to AASHTO 2012 and AASHTO 2020. JRA 2012 has the greatest design wind pressure value for all the cases. The main purpose of the study will be to apply wind loads to bridge structures using BNBC, and then compare these results with those obtained using other codes as mentioned in BNBC. Because there is no specific guideline for the use of wind loads in BNBC.

Keywords:- *COMPARISON OF WIND LOAD, BANGLADESH NATIONAL BUILDING CODE (BNBC), BNBC 1993 BNBC 2020, JRA, JRA 2012, AASHTO 2012, AASHTO 2020, ASCE 7-05, FACTORED TOTAL WIND PRESSURE.*

I. INTRODUCTION

Wind is a suddenly varying dynamic incident & a function of time & velocity. This is caused by the air flowing when air is moving from high pressure to low pressure. Before BNBC 1993 a simple empirical formula is used to determine wind load which do not consider the effect of surrounding objects and height of structure in wind pressure. This shortcoming has overcome in BNBC 1993 by introducing the concept of exposure category and gust factor. The effect of surrounding objects and height of structures is further upgraded in BNBC 2020.

The Bangladesh National Building Code (BNBC) was first organized in 1993 (Atique & Wadud, 2001). Subsequently, it has been updated to reflect changes in the building industry and a new gazette copy has already been published in 2021. A total change at wind load provision in BNBC 2020 is noticeable. The new wind load provision in BNBC 2020 is an adaptation from ASCE 7-05. The Japan Road Association (JRA) is known as the JRA code and was first published in 1947. This code has been continuously updated to account for changes in loading conditions and lateral load most importantly. In this study, it will be examined with a very well-known international code, that is American Association of State Highway and Transportation Officials (AASTHO). The two codes have different methods of calculating wind loads; however, both codes consider climate factors such as extreme environmental cyclones.

The Japan Road Association (JRA) code and the American Association of State Highway and Transportation Officials (AASHTO) code are commonly used in the design of roadways. Although there is no other civil engineering practice code in Bangladesh, the Bangladesh National Building Code is compared with the JRA and AASHTO codes for design purposes. It is essential to show that any project funded by JICA, World Bank and ADB, World Bank, JRA & AASHTO most of the time requires calculation using these codes.

This paper compares the provisions of wind load analysis given in BNBC 1993 and BNBC 2020. The justification for these results is made by examining other international codes, such as JRA 2012, AASHTO 2012 & AASHTO 2020. Engineers who use BNBC 1993 as their basis for calculations will gain from this comparative study an understanding of how the design wind load has changed in relation to the old code and how much factor of safety against wind disasters has been increased or decreased by adoption of the new code. The comparison of BNBC with other building codes will also inform whether our country's economic and population circumstances are being taken into account when these codes are being revised.

II. METHODOLOGY

For wind loads, BNBC 2020 has been compared with BNBC 1993, AASTHO 2012, AASHTO 2020, and JRA 2012. In order to determine wind loads, a number of design parameters are taken into account. First, the design wind load is determined by calculating velocity pressure. According to design considerations such as geographic location, structure type, exposure category, occupancy, importance factor, enclosure classifications, and many others, the calculation is made. When comparing wind loads with other codes, the assumed and considered values must be justified. The exposure of a structure to wind forces is a function of terrain type, vegetation and built-up environment in the surrounding area and pressure coefficient considers the direction of wind relative to the structure and roof slope.

In JRA 2012, design wind pressure at various heights is determined first based on geographical location, air density, structural geometry and other factors. The design wind pressure in AASHTO 2012 is determined by imputing the surface condition, structure type and geometry, as well as frictional factor. This is similar to the BNBC 1993.

Comparison of building codes with respect to wind force determination:

According to BNBC 2020 & ASCE 7-05

Design wind pressure,

$$q_z\left(\frac{kN}{m^2}\right) = 0.000613\ K_z K_{zt} K_d I\ GC_f V^2$$

Whereas,

$V = Wind\ velocity\ at\ 10.0m\ above\ low\ ground\ in\ m/s$
$K_z = Velocity\ pressure\ exposure\ coefficinet$
$K_{zt} = Topographic\ factor$
$K_d = Wind\ directionality\ factor$
$I = Structural\ importance\ factor$
$G = Gust\ effect\ factor$
$C_f = Force\ coefficient$

<u>According to BNBC 1993</u>

Design wind pressure,

$$q_z\left(\frac{kN}{m^2}\right) = C_C C_I C_Z C_p\ C_G V_b{}^2$$

Whereas,

$V_b = Wind\ velocity\ at\ 10.0m\ above\ low\ ground\ in\ km/hr$
$C_C = Velocity\ to\ pressure\ conversion\ coefficient$
$C_p = Gust\ coefficient$
$C_Z = Combined\ height\ \&\ exposure\ coefficent$
$C_I = Structural\ importance\ coefficient$
$C_G = Pressure\ coefficent$

<u>According to AASHTO LRFD 2012</u>

Design wind pressure,

$$P_D\left(\frac{kN}{m^2}\right) = \frac{P_B}{10000}\left(2.5V_0\frac{V_{30}}{V_B}\ln\frac{Z}{Z_0}\right)$$

Whereas,

$P_B = Base\ wind\ pressure$
$V_0 = Friction\ velocity$
$V_{30} = Wind\ velocity\ at\ 30.0\ ft\ above\ low\ ground\ in\ mph$
$V_B = Base\ wind\ velocity\ of\ 100\ mph\ at\ 30.0\ ft\ height\ in\ mph$
$Z = Structure\ height\ in\ feet$
$Z_0 = Friction\ length\ in\ feet$

AASHTO LRFD 2020

Design wind pressure,

$$P_Z\left(\frac{kN}{m^2}\right) = 2.56x10^{-6}\left(\frac{\left[\left(2.5\ln\left(\frac{Z}{0.0984}\right)+7.35\right)^2\right]}{478.4}\right)C_D G V^2$$

Whereas,

$C_D = Drag\ Coefficient$
$G = Guest\ effect\ factor$
$V = Wind\ velocity\ at\ 10.0m\ above\ low\ ground$
$Z = Structure\ Height$

JRA 2012

Design wind pressure,

$$P_Z\left(\frac{kN}{m^2}\right) = \frac{1}{2}\rho C_d G U_d{}^2$$

Whereas,

$C_d = Drag\ force\ coefficient$
$G = Guest\ response\ factor$
$U_d = Design\ reference\ wind\ speedat\ 10.0m\ above\ low\ ground\ in\ m/s$
$\rho = Air\ density\ in\ {}^{kg}/_{m^3}$

III. ILLUSTRATIONS

A. Basic wind speed V & V_b

In comparing the basic wind speeds given between BNBC 1993 and BNBC 2020, it is important to note that BNBC 1993 specifies fastest-mile wind speeds whereas BNBC 2020 provides basic wind speed in terms of 3-second gust wind speeds. The fastest mile speed is the average speed of a particle traveling with the wind over the distance of one mile. The 3-second gust speed is the peak gust speed averaged over a short time interval of 3 seconds duration. Both BNBC 1993 and BNBC 2020 provide basic wind speed associated with an annual probability of occurrence of 0.02 (50-year recurrence interval) measured at a point 33 ft (10m) above the mean ground level in a flat and open terrain. In both BNBC 1993 & BNBC 2020, tornadoes have not been considered in developing the basic wind speed distribution. Since square of the basic wind speed is used in determining

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sustained wind pressure, the increased wind speed results in approximately 26.58 percent increase in sustained wind pressure. Following equation is found satisfactory for converting fastest mile per hour wind speed into three second gust wind speed and used later for comparison.

Divisional percentage increase of wind speed according to BNBC 2020 from BNBC 1993:

Division	BNBC 2020 Basic Wind Speed V (m/s)	BNBC 1993 Basic Wind Speed V_b (m/s)	V/V_b		$(V/V_b)^2$	% Increase of Wind Speed
Barishal	78.7	71.11	1.11		1.22	22.48%
Chattogram	80	72.22	1.11		1.23	22.70%
Dhaka	65.7	58.33	1.13		1.27	26.85%
Khulna	73.3	66.11	1.11		1.23	22.93%
Rajshahi	49.2	43.06	1.14		1.31	30.58%
Rangpur	65.3	58.06	1.12		1.27	26.51%
Mymensingh	67.4	60.28	1.12		1.25	25.03%
Sylhet	61.1	54.17	1.13		1.27	27.24%

Table 1: Divisional percentage increase of wind speed according to BNBC 2020 from BNBC 1993

Whether the basic velocity pressure is prescribed or the design wind pressure, there is an average 26.58% increase in wind speed from the BNBC 1993 to the BNBC 2020. It's vital to keep in mind that when comparing the basic wind speeds between BNBC 1993 and BNBC 2020, BNBC 1993 specifies fastest-mile wind speeds, whereas BNBC 2020 gives basic wind speeds in terms of 3-second gust wind speeds. The average speed of a particle moving with the wind over a mile is the quickest mile speed. The peak gust speed averaged over a brief period of 3 seconds is the 3-second gust speed. It should be noted that the provided graphic (Chart-1 & Chart-2) only illustrates one possible scenario for how changing wind conditions may affect the design wind pressure estimate.

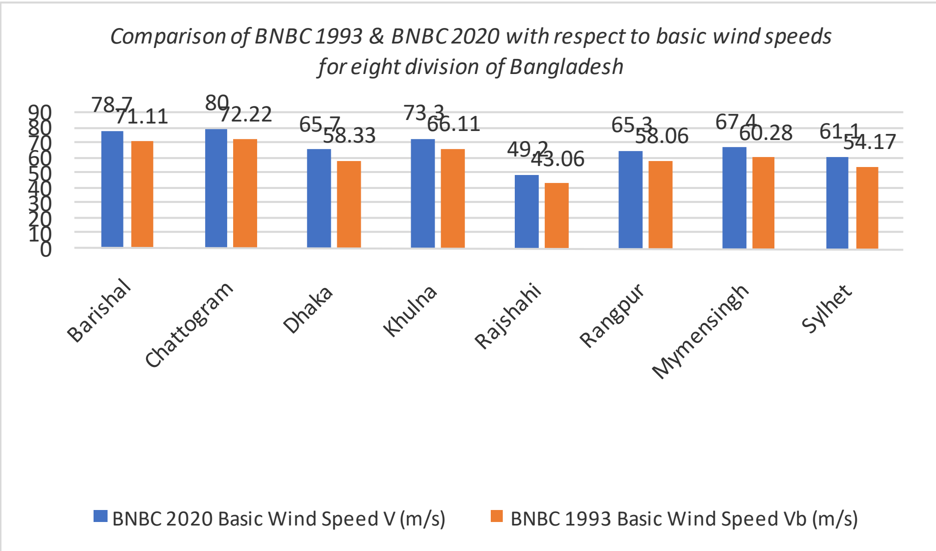

Chart 1: Comparison of BNBC 1993 & BNBC 2020 with respect to basic wind speeds for eight division of Bangladesh

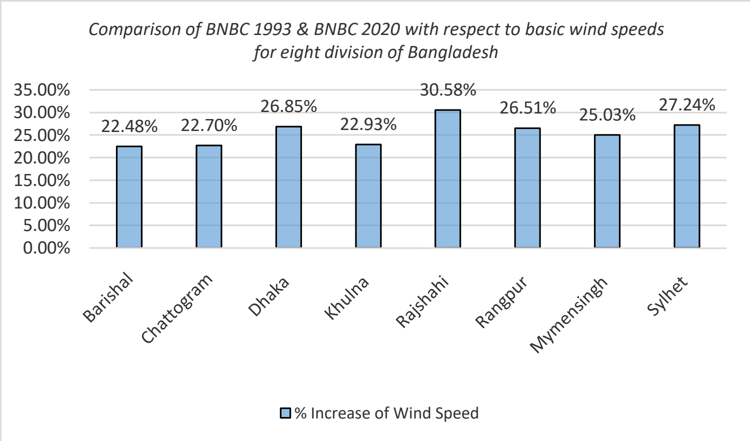

Chart 2: Percentage of increase the basic wind pressure of BNBC 1993 & BNBC 2020 with respect to basic wind speeds for eight division of Bangladesh

Average increase of the basic wind speed compares to BNBC 2020 refer to BNBC 1993 for eight division of Bangladesh is 25.54%.

A comparison of BNBC 1993 & BNBC 2020 with respect to basic wind speeds for different location of Bangladesh is given below;

Location	BNBC 1993 Basic Wind Speed V_b (kmph)	BNBC 2020 Basic Wind Speed V (m/s)	BNBC 1993 Basic Wind Speed V_b (m/s)	V/V_b	$(V/V_b)^2$	% Increase of Wind Speed
Angarpota	150	47.80	41.67	1.15	1.32	31.61%
Bagerhat	252	77.50	70.00	1.11	1.23	22.58%
Bandarban	200	62.50	55.56	1.12	1.27	26.56%
Barguna	260	80.00	72.22	1.11	1.23	22.70%
Barishal	256	78.70	71.11	1.11	1.22	22.48%
Bhola	225	69.50	62.50	1.11	1.24	23.65%
Bogra	198	61.90	55.00	1.13	1.27	26.66%
Brahmanbaria	180	56.70	50.00	1.13	1.29	28.60%
chandpur	160	50.60	44.44	1.14	1.30	29.62%
Chapai	130	41.40	36.11	1.15	1.31	31.44%
Chittagong	260	80.00	72.22	1.11	1.23	22.70%
Chuadanga	198	61.90	55.00	1.13	1.27	26.66%
Comilla	196	61.40	54.44	1.13	1.27	27.18%
Cox's Bazar	260	80.00	72.22	1.11	1.23	22.70%
Dahagram	150	47.80	41.67	1.15	1.32	31.61%
Dhaka	210	65.70	58.33	1.13	1.27	26.85%
Dinajpur	130	41.40	36.11	1.15	1.31	31.44%
Faridpur	202	63.10	56.11	1.12	1.26	26.46%
Feni	205	64.10	56.94	1.13	1.27	26.71%
Gaibandha	210	65.60	58.33	1.12	1.26	26.47%
Gazipur	215	66.50	59.72	1.11	1.24	23.99%
Gopalganj	242	74.50	67.22	1.11	1.23	22.82%

Habiganj	172	54.20	47.78	1.13	1.29	28.69%
Hatiya	260	80.00	72.22	1.11	1.23	22.70%
Ishurdi	225	69.50	62.50	1.11	1.24	23.65%
Joypurhat	180	56.70	50.00	1.13	1.29	28.60%
Jamalpur	180	56.70	50.00	1.13	1.29	28.60%
Jessore	205	64.10	56.94	1.13	1.27	26.71%
Jhalkathi	260	80.00	72.22	1.11	1.23	22.70%
Jhenaidah	208	65.00	57.78	1.12	1.27	26.56%
Khagrachhari	180	56.70	50.00	1.13	1.29	28.60%
Khulna	238	73.30	66.11	1.11	1.23	22.93%
Kutubdia	260	80.00	72.22	1.11	1.23	22.70%
Kishoreganj	207	64.70	57.50	1.13	1.27	26.61%
Kurigram	210	65.60	58.33	1.12	1.26	26.47%
Kustia	215	66.90	59.72	1.12	1.25	25.48%
Laksmipur	162	51.20	45.00	1.14	1.29	29.45%
Lalmonirhat	204	63.70	56.67	1.12	1.26	26.36%
Madaripur	220	68.10	61.11	1.11	1.24	24.18%
Magura	208	65.00	57.78	1.12	1.27	26.56%
Manikgonj	185	58.20	51.39	1.13	1.28	28.26%
Meherpur	185	58.20	51.39	1.13	1.28	28.26%
Maheshkhali	260	80.00	72.22	1.11	1.23	22.70%
Moulvibazar	168	53.00	46.67	1.14	1.29	28.98%
Munshiganj	184	57.10	51.11	1.12	1.25	24.81%
Mymensingh	217	67.40	60.28	1.12	1.25	25.03%
Naogaon	175	55.20	48.61	1.14	1.29	28.95%
Narail	222	68.60	61.67	1.11	1.24	23.75%
Narayanganj	195	61.10	54.17	1.13	1.27	27.24%
Narshingdi	190	59.70	52.78	1.13	1.28	27.95%
Natore	198	61.90	55.00	1.13	1.27	26.66%
Netrokona	210	65.60	58.33	1.12	1.26	26.47%
Nilphamari	140	44.70	38.89	1.15	1.32	32.12%
Noakhali	184	57.10	51.11	1.12	1.25	24.81%
Pabna	202	63.10	56.11	1.12	1.26	26.46%
Panchagarh	130	41.40	36.11	1.15	1.31	31.44%
Patuakhali	260	80.00	72.22	1.11	1.23	22.70%
Pirojpur	260	80.00	72.22	1.11	1.23	22.70%
Rajbari	188	59.10	52.22	1.13	1.28	28.07%
Rajshahi	155	49.20	43.06	1.14	1.31	30.58%
Rangamati	180	56.70	50.00	1.13	1.29	28.60%
Rangpur	209	65.30	58.06	1.12	1.27	26.51%
Shatkhira	183	57.60	50.83	1.13	1.28	28.39%
Shariatpur	198	61.90	55.00	1.13	1.27	26.66%
Sherpur	200	62.50	55.56	1.12	1.27	26.56%

Sirajganj	160	50.60	44.44	1.14	1.30	29.62%
Srimangal	160	50.60	44.44	1.14	1.30	29.62%
St. Martin	260	80.00	72.22	1.11	1.23	22.70%
Sunamganj	195	61.10	54.17	1.13	1.27	27.24%
Sylhet	195	61.10	54.17	1.13	1.27	27.24%
Sandip	260	80.00	72.22	1.11	1.23	22.70%
Tangail	160	50.60	44.44	1.14	1.30	29.62%
Teknaf	260	80.00	72.22	1.11	1.23	22.70%
Thakurgaon	130	41.40	36.11	1.15	1.31	31.44%

Table 2: Comparison of BNBC 1993 & BNBC 2020 with respect to basic wind speeds for different location of Bangladesh

Average increase of the basic wind speed compares to BNBC 2020 refer to BNBC 1993 for sixty-four district of Bangladesh is 26.58%

B. Factored total wind pressure comparison of different codes

The basic wind speed is determined on the basis of three second gust speed for all the discussed codes except for BNBC 1993. BNBC 1993 specifies basic wind speed on the basis of fastest-mile wind speed. So, for comparison wind speed of Cox's Bazar, the highest considered wind speed in Bangladesh, that is 260 km/hr (80 m/s) has taken for all codes. ASCE 7-05 is not compared separately as proposed BNBC 2020 gives factored total wind pressure exactly same to ASCE 7- 05. So, ASCE 7-05 and BNBC 2020 can be used interchangeably.

The effect of surrounding objects and height of structures are considered through various parameters in different building codes such as class, Terrain category, Exposure category etc. These parameters are not same for all codes. So, for comparison purpose surrounding conditions are broadly classified into three categories. They are urban, obstructed open terrain and unobstructed open terrain type areas which are defined in BNBC as exposure A, B and C respectively. All the codes are compared for these major surrounding conditions. For the comparison purpose only, the open terrain topography without hills with no cyclone prone area with 37.0m (equivalent to the height of a 10-storied building & bridge pier height) concrete structural height and carrying general importance (I=1.0) structural data is considered. Finally, all pressures are multiplied with respective wind load factor to calculate factored total wind pressure The following pressure variation is typical for structures of 37 m height. Both length and width of the structures have taken equal to 20 m. Corresponding parameters used in the respective codes are presented in the following table and the comparison results are presented graphically in the chart.

Applied Codes & Standards	**Velocity (m/s)**	**Velocity/Sustained Wind Pressure (kN/m^2)**	**Design Wind Pressure (kN/m^2)**
BNBC 1993	80	7.2453	11.0648
BNBC 2020	80	4.9422	6.8866
AASTHO 2012	80	-	10.1478
AASTHO 2020	80	-	6.7518
ASCE 7-05	80	4.9422	6.8866
JRA-2012	80	-	11.9701

Table 3: Different design wind pressure according to the international codes

Since the main land of Japan is frequently affected by cyclones and other environmental forces, such as the typhoon that caused the issue, JRA rules follow the greatest design wind pressure. As a result, the established equation in JRA code takes the cyclone phenomenon into account. The investigation also reveals that the designed wind pressure in various exposures is slightly higher according to BNBC 1993 than BNBC 2020, despite the fact that it shows that the percentages of the basic wind speed increase according to BNBC 1993 and BNBC 2020 significantly increased compared to the recent codes. The BNBC 2020 code, however, does not significantly differ from ASCE 7-05, leading to about the same design wind pressure.

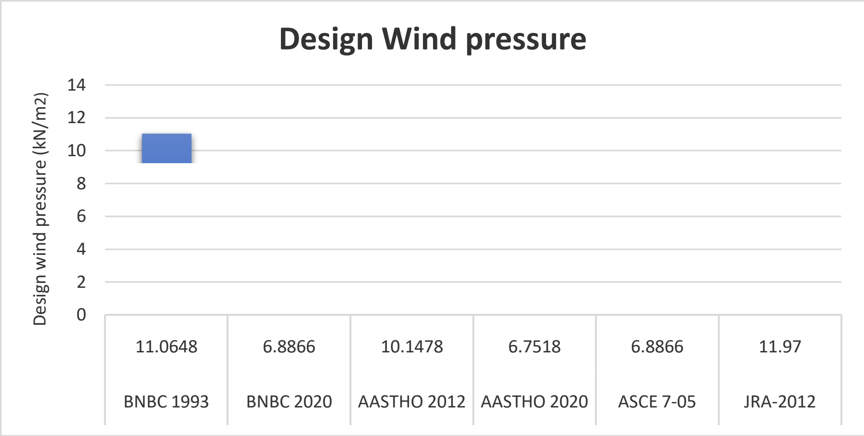

Chart 3: Comparison of design wind pressure according to the international codes

IV. CONCLUSIONS

Before BNBC 1993, a straightforward empirical formula was used to calculate wind load, which ignored the impact of nearby objects and the height of nearby structures on wind pressure. By introducing the concepts of exposure category and gust factor, this flaw was fixed in BNBC 1993. In the planned BNBC 2020 wind provision, the impact of nearby objects and structure height is further upgraded. Because of this, BNBC 2020 finds that the Wind load in urban areas (Exposure A) is significantly larger (6–11%) than BNBC 1993. However, BNBC 2020 revealed that the wind load in exposed B and C (obstructed and unobstructed open terrain type areas) was significantly lower (1–15%) than BNBC 1993. Further wind load according to BNBC 2020 is found exactly equal to wind load according ASCE 7-05 & AASTHO 2020 and considerably less (20-38%) than 2012. Typhoon and other extreme weather impacts are taken into account, and JRA assigns a larger value (5–23%) when compared to all the code that has been mentioned. In Bangladesh, there is no prescriptive code for assessing bridge-type structures. Instead, design pressure in accordance with BNBC 2020 or the value of wind speed are used to account for wind forces on substructures and superstructures in wind load analyses. This example demonstrates that while using the BNBC 2020 value for a wind load study of a bridge structure is customary, it is also necessary to use the AASTHO 2020 in order to provide cost-effective and excellent structural findings. For any Bangladeshi design, it will not be practical to take wind pressure into account in accordance with JRA 2012.

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