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INVESTIGATING MULTIPLE DEBRIS IMPACT LOAD AND ROLE OF VEGETATION IN PROTECTION OF HOUSE MODEL DURING FLOODS

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Abstract- Storms and flooding caused significant damage to buildings. The waterborne debris created during such natural disasters will cause significant damage to the many structures unless they were designed for these loads. Flood field survey findings suggested large objects such as wooden logs, cars, vessels, storage barrels, and other containers intensify the damage. For this cause, a driftwood approach was established to test tree washout, floating trees movement, and collisions with the house model. This paper addressed the findings of experimental analysis on the frameworks to measure the debris impact, hydrostatic and hydrodynamic forces. It also analyzed the formulas, which were defined with the experiment results in the recently released design guidelines (FEMA P-646, 2012). Moreover different hydraulic jumps were observed while observing water surfaces in three different situations (without house model and vegetation, only vegetation and with vegetation and house model). This resulted in an energy reduction of up to 18 % for only vegetation case and 19 % for vegetation with house model.

Keywords-Experimental modeling, Flood born debris, Floods, Flume experiment, Vegetated channel.

1 INTRODUCTION

Flood is often a huge volume of water overflowing outside of its normal parameters. Flood impacts can cause tremendous damage including buildings, properties, and human existence. Flood is the elevated volume of fluid (typically water) from a nearby body of water that saturates the ground which is typically dry throughout the year. Most frequent causes of inland flooding occur near a river or stream with intense rains over a watershed, either a reservoir or a levee breach, or snow covers in the northern areas rapidly melting. Flooding is often triggered by tsunamis or hurricanes which are known as tidal flooding because they only strike marine areas and do not spread far across the surface. Furthermore, the findings found that the main source of the destruction was due to the hydrodynamic force and/or impact force that the debris had created [1], [2]. Capable of understanding the loads caused by floods will thus help to improve the design and installation of flood-resistant buildings. The construction and building guidelines currently being pursued by [3] are recommending specific methods to characterize the debris effect load, but these are not well developed.

The structural susceptibility of buildings in flood flows is generally modeled Depends on the water depth and flow rate together. The Guidelines were extracted from historic flood data but their empirical investigation is severely minimal. There's a need to address for the significant number of complexity associated in such procedures motivates the recent positioning towards the more established and simple deterministic approaches to risk assessment. Past research has revealed by post-disaster surveys that vegetation helps to reduce the adverse consequences of natural disasters. Few prominent ones around the world are discussed briefly here. Both vegetation density and thickness on the upstream side raise the increase in the backwater. Depending on its configuration and thickness a forest can offer sufficient opposition to a flood force experimentally and numerically studied the influence of vegetation density and reported that both the water level and velocity behind the vegetation are greatly decreased by rising the aspect ratio of the vegetation [4]. The floating debris taken by a flood can intersect with buildings and then cause them additional damage. Vegetation is not only vital, but several factors are crucial for catastrophic variations in floods. Experimental analysis was conducted and it was found that even in sparse situations, two rows Vegetation system more driftwood than the single row Vegetation. As aspect ratio is enhanced, more driftwood is grown. Inland forest trees can handle the stress of floating debris and can also withstand the trapped debris as per velocity and Froude number of flow [5]. Tanaka and Ogino [6] studied in detail about the Impulse force on the locally constructed houses by the colliding of water-born floating debris. This paper studies the impact of waterborne debris on the local model house in the presence and absence of vegetation on the structural buildings

During floods, debris collide with houses that exist in the route way of flood water, generating an impact, hydrostatic and hydrodynamic loading on houses. Debris transported by floodwater strike residential or other structures in the floodplain. These impacts reduce the velocity of the debris and impart a force to the structure. The magnitude of the force can be large enough to cause substantial, or even catastrophic, damage to the structures. The aim of this research is to measure impact forces on model house due to floating debris based on mass and velocity of prototype woody debris by experimental setup as well as numerical analysis.

2 FORCES ON BUILDING DUE TO FLOOD BORN DEBRIS

Building structural fragility based on both the demand (loading) and structural sustainability (capability). This research is focused on the loading of the structure caused by the flood. During severe disasters, the development of floodplains of high flood-induced dangerous areas can be exposed to a range of forces, involving impact forces hydrostatic force and hydrodynamic force.

2.1 Impact force

FEMA P-55(2011) proposed an equation to investigate impact force which is

$$F_i = WVC_DC_{str}C_B \qquad (1)$$

In which F_i refers to the impact force, W stands for the debris weight, V is the debris velocity, $C_DC_{str}\ and\ C_B$ are the depth, building structure, and blockage coefficients, respectively. Based on the flow depth the depth and blocking coefficients range from 0-1. In the meanwhile, C_{str} is based on the form of structure, the direction, the natural phase, and the period of the impact. The coefficients provided in Eq.1 are derived from the findings of the laboratory and the conclusions about engineering.

The FEMA P-646 (2012) [7] provided the formula to calculate debris impact forces that differed from the previous version, and the following is:

$$F_i = 1.3\ u_{max}\sqrt{km_d(1+c)} \qquad (2)$$

For which, u_{max} refers to the maximum velocity of flow close to the structure. The velocity of the moving debris is believed to be equal to the velocity of flowing water. k,m_d, c refers to the combined rigidity of the impacted structures, the mass of the debris, and the hydrodynamic mass coefficient respectively. As per FEMA P-646 [7] for wooden debris, for debris that flows parallel to the flow direction, $c = 0$, for debris with a transverse orientation towards flow direction $c = 1$, Whereas for debris such as 20-ft and 40-ft cargo ships, $c = 3$ and $c = 2$ respectively.

2.2 Hydrostatic force

The horizontal hydrostatic force is extracted from the change in water level on wall upstream and downstream sides. It is given per unit length by:

$$F_{h,static} = \frac{1}{2}\rho g\ (h_{us}^2 - h_{ds}^2) \qquad (3)$$

Where ρ and g are the density of water and the gravitational acceleration respectively while as h_{us} and h_{ds} are referred to as depth of water upstream and downstream of the wall.

2.3 Hydrodynamic force

Hydrodynamic force is resulted from a composite of inertia and drag, while as it depends on both kinematics and dynamics of the flow and characteristics of structure respectively. The following concise expression is, in general, followed for the Hydrodynamic force per unit length is

$$F = C_d.\rho.g.h.u^2 \qquad (4)$$

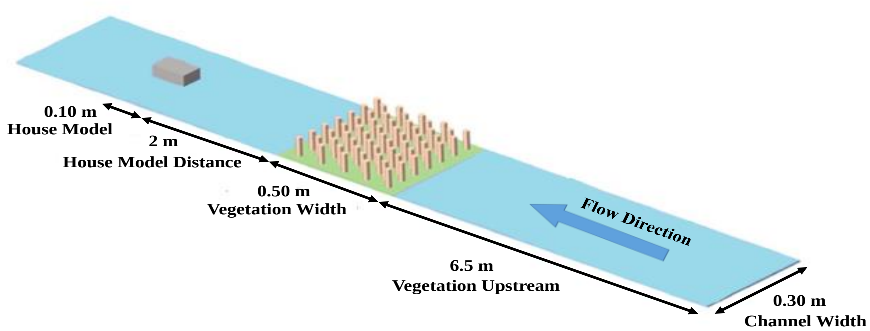
Where C_d is the drag coefficient, h and u are the depth of water near wall and velocity component orthogonal to the object respectively.

3 EXPERIMENTAL PROCEDURE AND FLUME CHARACTERISTICS

In a glass-sided water flume (constant bed slope 1/500) that is 11 m long, 0.30 m wide, and 0.34 m high at the University of Engineering and Technology Taxila., laboratory tests were performed under various conditions. The schematic figure of the water channel is shown in Fig.1 (a). A small scale (1/45) of a wooden house was designed to test the relationship of the bore structure and the effect of debris on the structure. This building has a height of 0.15 m, a width of 0.10 m, and a length of 0.10 m and provided an equal building height of 675 cm, a length of 457 cm, and a real building width of 457 cm. As per the horizontal impact of debris, three equations (Eq.2, 3, and 4) were used to measure the reaction forces on the house model. A high-speed digital camera was used to monitor the behavior of the structure model and the velocity, direction, and effect of debris flow with the house model.

Table 1: Experimental Condition

Case No	Initial Froude Number (*Fr*)	Vegetation Density (*G/d*)	Vegetation Thickness (dn)	Vegetation Type	Building Distance (cm)
1	1.12	1.09	150	Transition	200



(a)

(b) (c) (d)

Figure 1: Experimental setup (a) Schematic diagram of the vegetated open channel (b) details of vegetation arrangement (c) house model and (d) types of debris

Five pieces of wooden planks in the staggered arrangement shown in Fig. 1(b) each with various sizes, diameter, and weights, was used to measure the effect caused by the wood debris. Moreover, the wooden house model in the open channel is shown in Fig.1 (c). The debris weight was then selected to fit target weights of 13.8 g, 15.8 g, 19.4 g, 45 g, and 33.9 g to reflect the debris scale of 1/45. The complete detail of debris used in the present experimental work is given in shown in Fig.1 (d) and table 2.

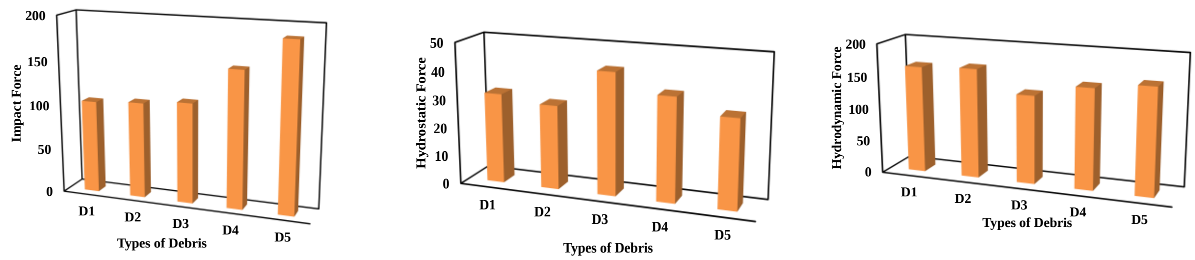
Table 2: Debris used in the present work are

Debris Type	**Length (cm)**	**Diameter (cm)**	**Weight (g)**
D1	24.5	0.75	13.8
D2	23	1	14
D3	26.5	1.25	19.4
D4	14	1.7	33.9
D5	24	1.7	45

4 RESULTS AND DISCUSSION

4.1 Debris Impact, Hydrostatic, and Hydrodynamic Forces.

Fig. 2 represent the experimentally derived values on the composition of the debris, and they were determined using the formulas given in the design guidelines. FEMA P-55[7] (Eq. 2, 3, and 4) to investigate the impact force (Fig.2a), Hydrostatic force (Fig.2b), and Hydrodynamic force (Fig.2c) of all debris given in table 2. The Forces displayed in Fig. 2 are based on the velocity of the debris that is measured experimentally. For wooden log debris, FEMA P-646 [7] suggested C=0 and $k=2.4\times10^6$.



(a) (b) (c)

Figure 2: Comparison of waterborne debris (a) impact force (b) Hydrostatic force (c) Hydrodynamic force

Fig. 2 (a) revealed that the impact force was directly related to the mass of debris. The highest value of impact force was observed for D5 while as the minimum value for the D1 debris. Similarly, for the hydrostatic force which depends upon u/s and d/s water head, D3 showed the highest value for its larger length (26.5 cm) as compared to other debris (D1, D2, D4, and D5). D2 debris showed lower value because of shorter length (23 cm) and lower value of diameter (1 cm). The lower magnitude of hydrodynamic reflects the lower values of water accumulation at the upstream of the house model. For the dynamic force, the D2 type of debris showed the highest value compared to D3 which showed the lowest value because this force depends on the flow velocity. As the flow velocity and debris velocity were the same, so it was verified from the experiment that higher flow depth due to the larger value of length reflect the lower value of velocity shown in Fig. 2(c).

4.2 Water Surface Profiles (WSP)

Three different cases were considered to reflect the water surface profile that includes the without vegetation and house model, only vegetation and vegetation with house model profiles shown in Fig. 3. The experimental domain was taken at some distance from the channel inlet to prevent disturbance created at the channel inlet. The undulation in water depth was achieved at the upstream of only vegetation case and vegetation and house model case. It illustrated that the single hydraulic jump was created at the downstream of vegetation in only vegetation case and two hydraulic jumps were created at the downstream of vegetation and house model in vegetation and house model case.

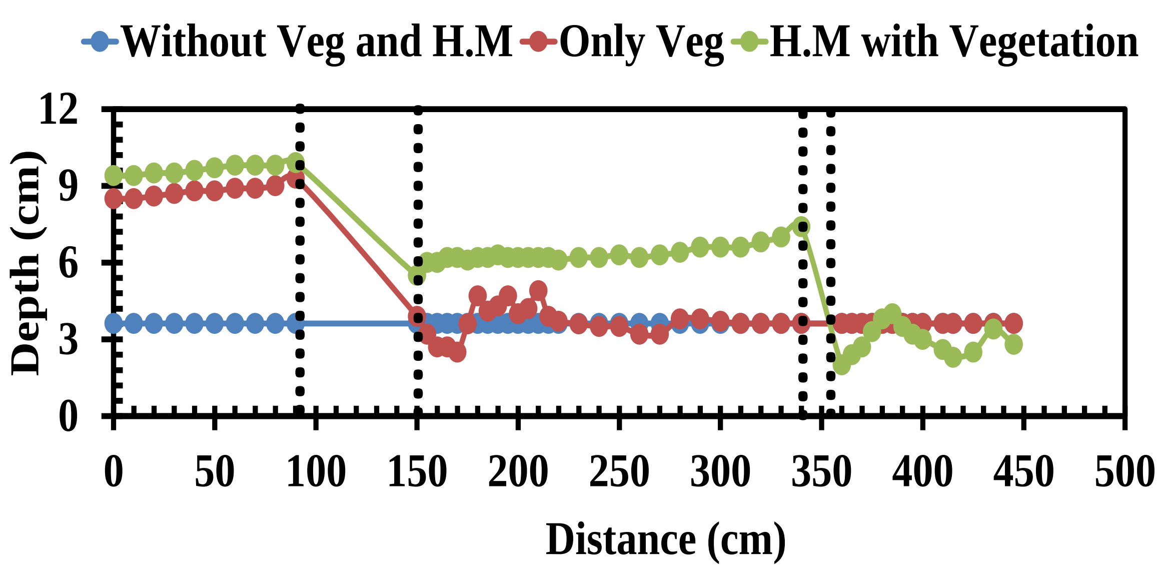


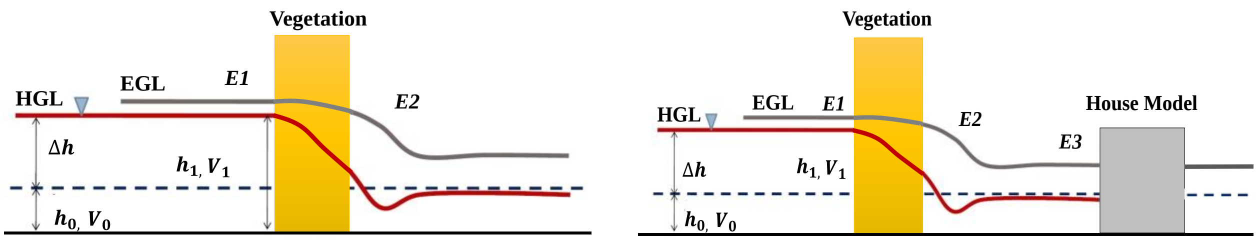
Figure 3: water depth measurement of the experimental domain

4.3 Energy Dissipation

It involved the specific energy E, flow velocity V, and water depth y can be written as Chow [8].

$$E = y + \frac{V^2}{g} \qquad (5)$$

In which y is water depth and where g is gravitational constant. This equation will be used to calculate energy dissipation, which is the difference between upstream and downstream energy. In the current study, we consider the dissipation of energy in terms of the total loss of energy ($\Delta E = E1\text{-}E2$) and relative total loss of energy (ΔE / E). Water depth in the presence of only vegetation can be observed in Fig. 4(a). Moreover, the energy dissipation was upto18 % at the downstream of the transition arrangement of vegetation.



(a) (b)

Figure 4: Flow behavior and difference of different parameters in the presence of (a) only vegetation and (b) vegetation with a house model.

Moreover in the presence of a house model with vegetation energy variation of energy in the form of dissipation was observed up to 19% shown in Fig. 4(b). It means that that vegetation played a vital role to dissipate the energy.

5 CONCLUSION

Evaluating the structures' stability in flood-prone areas is a crucial concern in evaluating flood-induced risks, particularly for its strong correlation of life loss during these tragic events. Keeping this in mind, a new series of studies has been carried out at UET Taxila to spread further light on flood-induced load dynamics and their impact on houses and to establish state-of-the-art measurements for the community. This research then compared experimental findings with the FEMA P-646 (2012) calculations which were suggested. It was noted during the analysis that the equation suggested by FEMA P-646 offered a better and more precise calculation of the forces of impact, hydrodynamic and hydrostatic. Initial findings indicated that impulsive loading may be considerably higher than those expected by current forecasting methods and should be seen as potentially important when evaluating the vulnerability of existing structures and constructing flood-proof buildings

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