World Applied Sciences Journal 12 (8): 1165-1171, 2011
ISSN 1818-4952

Dynamic Pressure of Flip Bucket Jets

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Abstract: In this study, dynamic pressures due to impact of a ski jump out of a flip bucket downstream of a chute spillway model have been studied. Experiments were performed for five discharge (0.11, 0.18, 0.25, 0.32, 0.39 m^3/s per unit width) and four jet impact angles (0°, 30°, 60°, 90°). Fluctuation of dynamic pressure was measured using a 250 mbar pressure transducer. Discharge (q), horizontal and vertical distance from the peak to jet impact location (L, H-h) and angle impact in downstream (è) were considered as the main parameters affecting the dynamic pressure. Results showed that pressure coefficient is highly sensitive to horizontal and vertical distances to impact location as well as to the impact angle. Using dimensionless parameters, a power function was correlated for calculation of the dynamic pressure for variable impact angle.

Key words: Dynamic pressure · Sky jump · Jet impact

INTRODUCTION

The impingement of a turbulent jet on a solid surface finds application in a number of engineering problems. Jets issuing from hydraulic outlets, weirs, ski jump and various spraying devices are examples of such problems [1]. The energy of high-velocity falling jets is generally dissipated in natural or concrete lined plunging pools. The hydrodynamic loading produced by jet impact on the pool bottom directly influences on its design. The loading is governed by characteristics of jet outlet and trajectory as well as jet deformation in the air and water in case of high level of tail water. The rapid diffusion of the jet in the pool dissipates the energy of the falling jet and attenuates pressure fluctuations at the base of the pool. If the pool is deep enough, an unlined basin can be used for the plunge pool. The area of flow has considerable effect on pressure distribution. Several researchers have investigated the effects of the flow boundary on the jet's pressure and velocity fields. A comprehensive study of plane and circular, oblique and vertical jet impingement on a flat and smooth surface can be found in [2-5]. They proposed three distinct flow regions: the free jet, the impingement jet and the wall jet region (Fig. 1). In region I, the flow characteristics are, for all practical purposes, identical to those of a free jet. This region therefore is referred to as the "free jet region". In region II, the flow undergoes considerable deflection and at the end of this region becomes parallel to the wall assuming a pattern very similar to what is known as the wall jet. It is appropriate therefore to refer the region II as the "impingement region" and to region III as the "wall jet region". It is logical to expect transitions between these regions.

The main objective in region I was to determine its extent. In region II, where the static pressure is generally higher than the ambient pressure and the velocity vector assumes a relatively large angle with the initial jet direction, the main objective was to study the velocity and pressure fields. The wall shear stress was also studied.

In the wall jet region, the objectives were to investigate the velocity field, the jet thickness and the distribution of the wall shear stress. The impinging circular jet has been studied in [6-8. These investigations were mainly concerned the free jet and wall jet regions with only some preliminary measurements in the impingement region. [7] attempted an inviscid rotational flow type solution for the impingement region. For the plane jet, [9] reported measurements for impingement at small angles. His work was mainly concerned with the wall jet forming after impingement.

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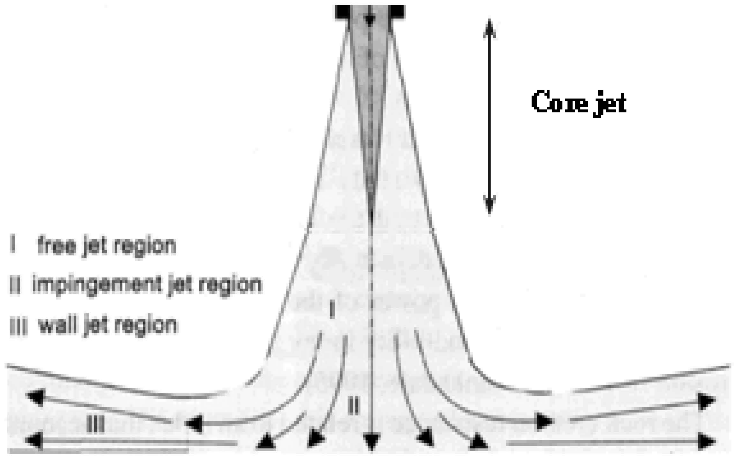

Fig. 1: The main regions of jet impingement [2].

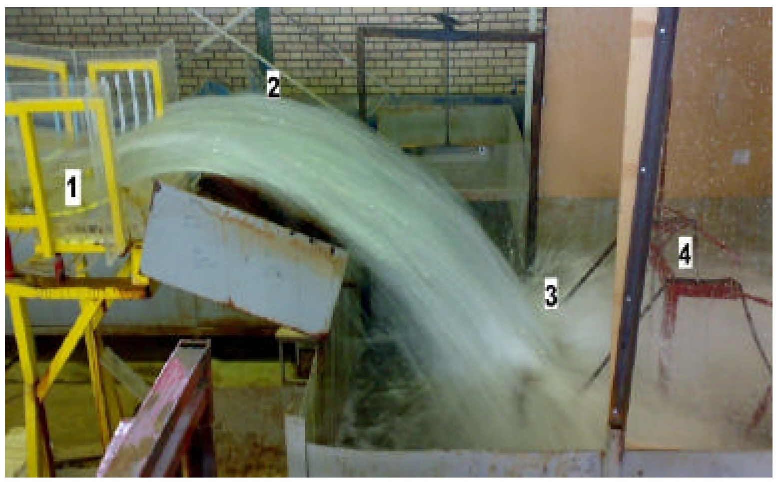

Fig. 2: Experimental setup, (1) Flip bucket, (2) peak of the jump, (3) jet impact location, (4) Platform

Also for the plane case, [10] reported results for different angles of impingement including the case of normal impingement. Their work was also concerned mainly with the wall jet region. The most severe hydrodynamic action of the flow occurs in the impingement region, near the solid boundary. There, the hydrostatic pressure of the free jet region is progressively transformed into highly fluctuating stagnation pressures and an important wall shear stress. Hence, the impingement region is directly related to scour formation due to the pressure fluctuations that are generated enter underlying rock joints and progressively break up the rock mass. During the 1980's and 1990's, influence of time-averaged dynamic pressure [11-13] and instantaneous dynamic pressure [14-15] were studied. [16] investigated pressure differences over and under concrete slabs and rock blocks. Dynamic pressures at plunge pool bottoms and stilling basins have first been studied in the 1960s. Transfer of these pressures to joints between the slabs or blocks was found to result in catastrophic failure by dynamic ejection. [17-20] demonstrated that the scour process depends on various parameters, i.e. jet discharge, densimetric jet Froude number, jet impact angle, jet air content, upstream flow, tailwater depth above the bed, and granulometric characteristics of the sediment. [5] developed a semi-empirical model to compute the temporal variation of scour depth for short abutments. [21-22] studied the geometrical and hydraulic parameters governing the scour process and proposed relationships to predict maximum scour hole depth without protection measures. [23] extended previous results to the three-dimensional scour hole arrangement in clouding hydraulic and granulometric effects. They added to the effect of the relative scour hole width, both the static and dynamic scour hole depths.

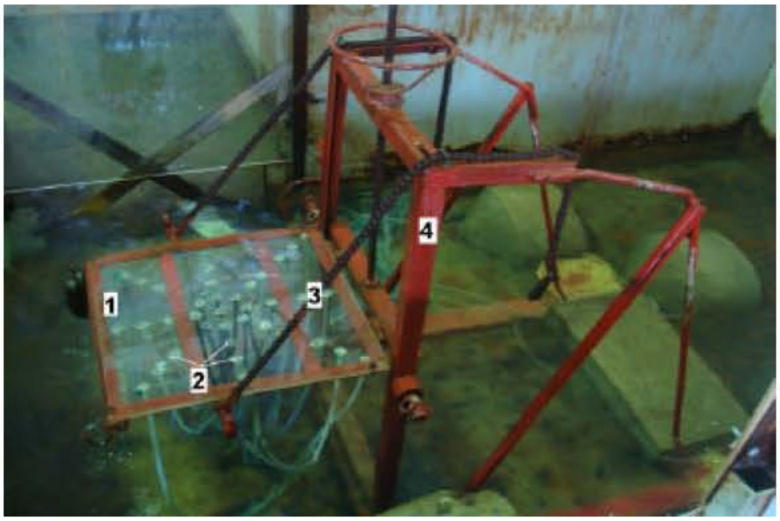

Fig. 3: (1) Flat plate, (2) Hollow, (3) Rotor arm, (4) platform

In many cases, the ski jump may impact the gorge and river valley wall at different angles before entering the plunging pools. The jet pressure can cause cracks and eventually fractures in the wall, and hence damages to the dam and construction facilities. This study investigates dynamic pressures due to jet impact with variable angles and discharges.

Experimental Setup: The experiments were conducted on a sky jump out of a flip bucket at the end of a 10m long and 0.5 width chute spillway model located in Hydraulics Laboratory of the Shahid Chamran University of Ahvaz. The jet impacted a 50 × 50 cm plexiglas flat plate sat on a platform having 37 piezometric tabs to measure dynamic pressure of the impact (Fig. 2). The platform and its rotor arm were used to adjust the location and angle of impact (Fig. 3). The piezometric tabs were connected to a 1 Bar pressure transducer (model WIKA S-11, with accuracy of 0.25% and stability of 1%) and a data acquisition system.

The pressure signal was sampled at 50Hz for 300 seconds. Discharge was measured using a rectangular weir at the end of water circulation system. The range of discharges was from 0.11 to 0.39 cubic meters per unit width of the flip bucket. The effective parameters on the dynamic pressure are assumed as follows:

$$f(P,H,h,L,B_j,B_i,q,\alpha,\theta,V_j,g,\rho_w,\mu_w) = 0 \quad (1)$$

Where P= Dynamic Pressure, H, L and h = are shown in Fig. 4., B_i= Jet width before leaving the bucket, B_j=Jet width at the impact, q=Unit flow discharge, α=Jet throw angle, θ=Jet impact angle, V_j=Jet velocity before impact, g=Acceleration due to gravity, ρ_w=Water density, μ_w=Water dynamic viscosity. A relation between effective dimensionless parameters for dynamic pressure can be as follow,

$$\frac{P_m}{V_i^2/2g} = f\left(Fr_i,\theta,q_j/q_i,(H-h)/L\right) \quad (2)$$

Pressure Fluctuation in Jet Impact Location: Fluctuation is the main characteristic of dynamic pressure. It is necessary to record fluctuations in proper frequency. The dynamic pressure fluctuations were recorded at 50 Hz frequency for variable discharges and jet impact angles of θ = 0°, 30°, 60° and 90°. Fig 5 illustrates pressure fluctuations for flow rate of 0.11 m^2/s/ and impact angles 0°, 30°, 60°, and 90° (for 10 second).

The pressure fluctuation reduces as θ is decreased. While maximum of average pressure and fluctuation occurs for θ =90°, negative pressures (suction) develop with decrease of θ and a negative average pressure was recorded for θ =0°.

Mean Dynamic Pressures: The mean dynamic pressure on the flat plate is described by a pressure coefficient, Cp as,

$$C_P = \frac{H_m}{V_j^2/2g} \quad (2)$$

Where H_m is the mean head recorded by transducer and data acquisition system. Having discharge, Vj is calculated using continuity equation and the jet cross section before the impact. Figure 6 shows C_P verses unit discharge for different angle of impact. C_p decreases with decrease of impact angle. For θ = 0, C_p is Negative.

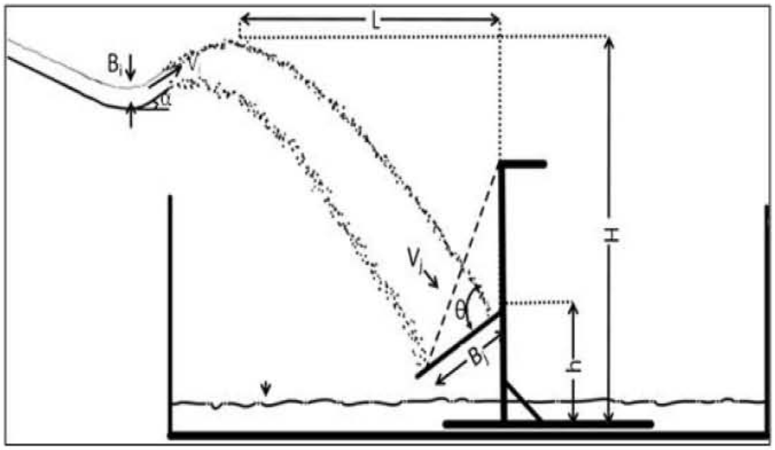

Fig. 4: Effective parameters on dynamic pressure of impact

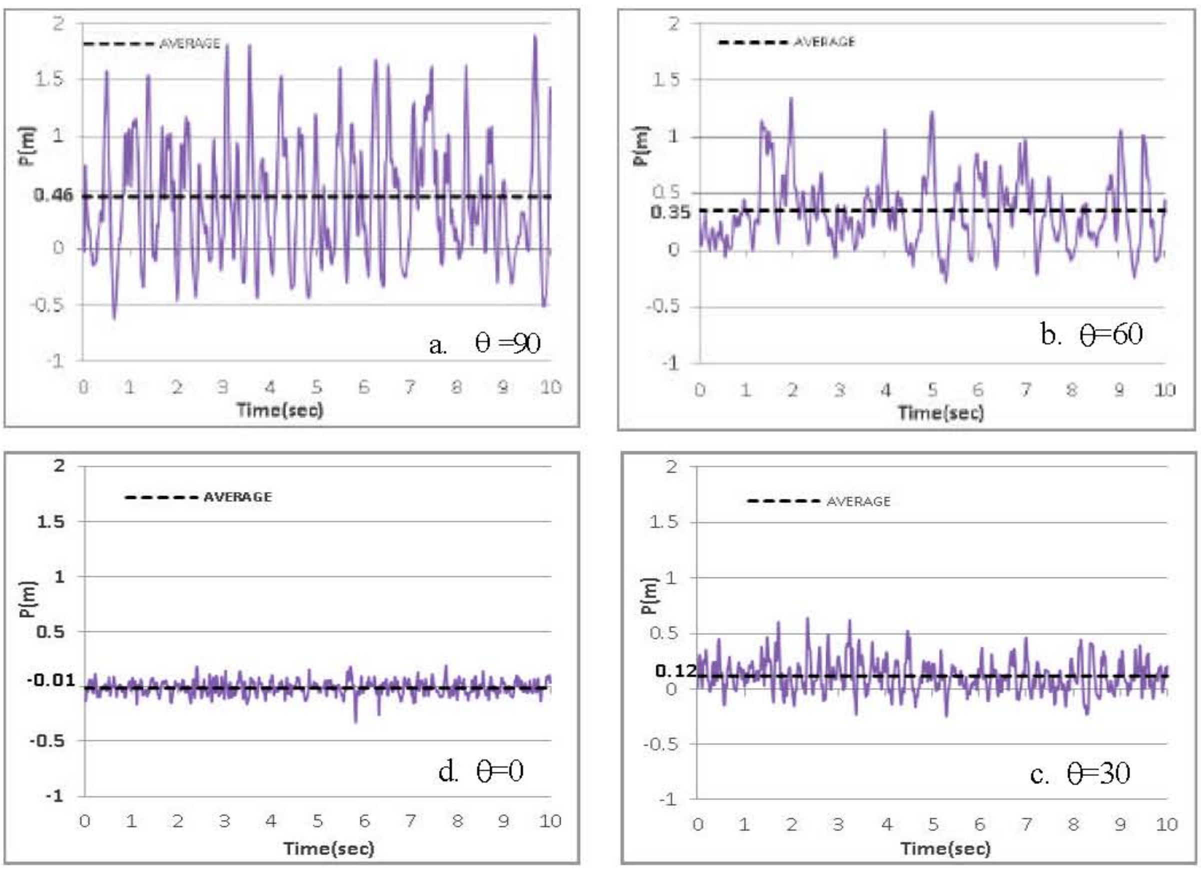

Fig. 5: Pressure fluctuation recorded for flow rate of 0.11 m^2/s and difference jet impact angles

RMS of Pressure Fluctuations: The root mean square of pressure fluctuations (H') is a powerful tools to describe pressure effect on plunging pool. The root mean square pressure fluctuation coefficient (C'p) is defined as:

$$C'_P = \frac{H'}{V_j^2/2g} \tag{3}$$

As it is shown in Fig. 7, C'_p increases with water flow rate and the jet impact angle. Highest fluctuation amplitude of C'_p was occurred for θ =90°.

Extreme Dynamic Pressures: The variation of the extreme positive and negative pressure coefficients (C_p^+ and C_p^-) with discharge per unit width (q) are shown in Figs. 8 and 9. They are defined as maximum of minimum

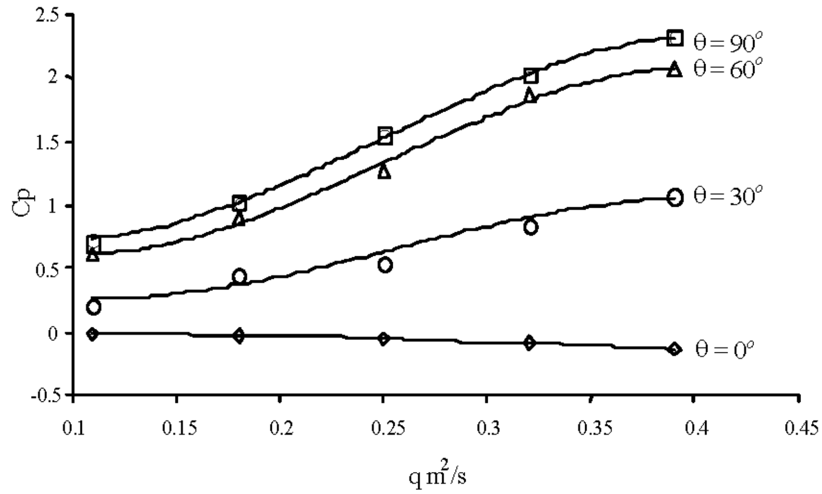

Fig. 6: Pressure coefficient Cp versus unit flow discharge at difference jet impact angles

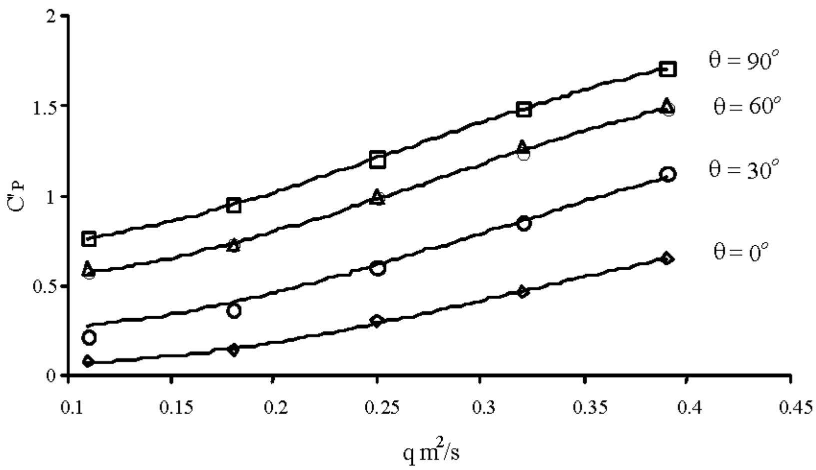

Fig. 7: The root mean square pressure fluctuation coefficient C'p versus to unit flow discharge at difference jet impact angles

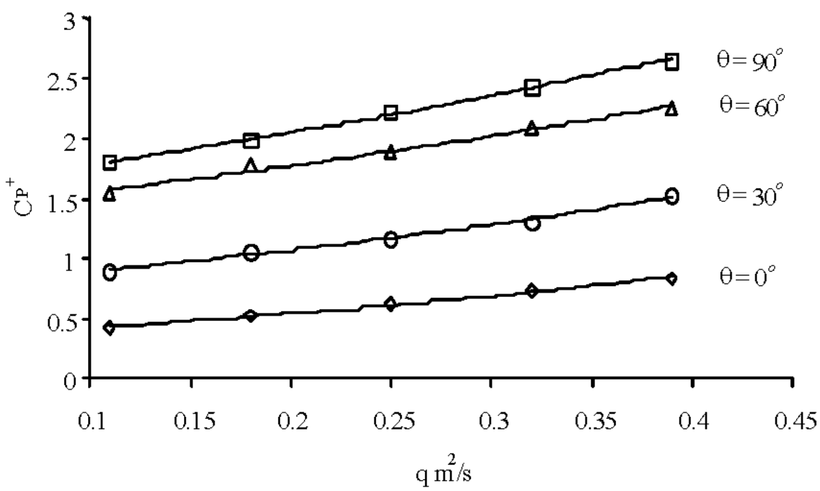

Fig. 8: Non-dimensional positive extreme dynamic pressure value C_p^+ versus to unit flow discharge at difference jet impact angles

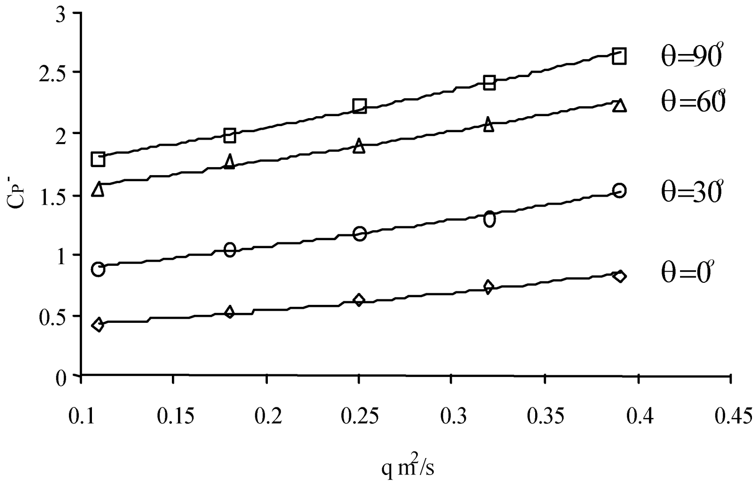

Fig. 9: Non-dimensional negative extreme dynamic pressure value C_p^- versus to unit flow discharge at difference jet impact angles

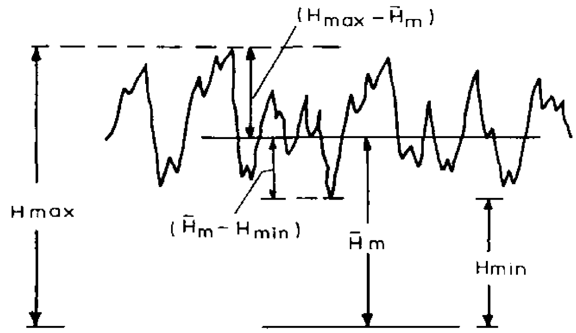

Fig. 10: The mean, maximum and minimum instantaneous values of dynamic pressure

value of pressure fluctuation (H_{max}, H_{min}) from the mean dynamic pressure (H_m) divided by the kinetic energy of the water jet as follow,

$$C_P^+ = \frac{H_{max} - H_m}{V_j^2/2g} \quad (4)$$

$$C_P^- = \frac{H_m - H_{min}}{V_j^2/2g} \quad (5)$$

Same results as before can be seen in the figures for increase of C_p^+ and C_p^- with discharge and angle of impact. A sample of dynamic pressure recorded by data acquisition system is also shown in Fig. 10.

Maximum Pressure (P_{max}): As mentioned, the dynamic pressure and the discussed parameters have a relationship in form of Eq. 1. The correlation of dimensionless maximum pressure $P_{max}/(V_i^2/2g)$ with rest of parameters results following equation,

$$\frac{p}{V_i^2/2g} = \theta^{0.94} \times \left(\frac{H-h}{L}\right)^{0.43} + 0.06 \quad (6)$$

Equation 6 can be used to estimate maximum pressure as results of dynamic impact of a sky jump on the valley sidewall or plunging pools bed or wall with any angle of impact.

CONCLUSIONS

Results of this study can be very useful to prevent erosion of valley side wall and design of plunging pools downstream of chute spillway and sky jumps. Following conclusions were obtained in this study;

- The maximum pressure of impact occurs at center of jet impact and decreases with the distance from the center.
- Maximum of pressure fluctuation and maximum of average pressure have been occurred at impact angle of 90°. They are decreased with reduction of the impact angle.

- The RMS of pressure fluctuations (C'_p) increases with increasing discharge and angle of impact from 0° to 90°.
- The Extreme dynamic pressure values of C_p^+ and C_p^- are increased with increasing water jet discharge and angle of impact.

ACKNOWLEDGEMENT

The authors would like to acknowledge Chamran University of Ahwaz and the Centre of Excellence on Operation Management of Irrigation and Drainage Networks for financial support and facilitation of the experiments.

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