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# The study on solitary waves generated by a piston-type wave maker

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ABSTRACT

The focus of present study is on how to generate solitary waves in a wave flume using a piston type wave maker. Experimental observations are implemented to evaluate the stability of the generated solitary waves. A better "stability" implies that the generated solitary wave can travel a longer distance without an obvious decay. Another discovery of this study is the imperfect fitness of wave paddle to the flume could degenerate the solitary wave heights in a great amount. Numerical simulations are carried out to verify this. This study concludes that the method proposed by Wu et al. (2014) is effective for generating solitary waves, even if the wave paddle fits the wave flume imperfectly.



## 1. Introduction

It has been more than one century since the remarkable discovery of solitary waves was made. Till now, many studies on the characters and behaviors of solitary waves have been done via experimental approaches. An essence of these studies is how to generate solitary waves in a wave flume. Methods for laboratory generation of solitary waves include dropping weights (Hammack and Segur, 1974; Wiegel, 1955), displacing a given mass of water by a rising bottom (Daily and Stephan, 1952), releasing a prescribed amount of water behind a barrier (Kishi and Saeki, 1966), and horizontal movement of a vertical paddle by a piston-type wave maker (Camfield and Street, 1969; Goring, 1978).

Among these methods, Goring's method which prescribes the velocity of the wave paddle of a piston-type wave maker has for several decades been the most commonly employed. Nevertheless, one could find in some studies that Goring's method only works for small solitary waves. When a higher solitary wave is generated, a slight depression of the free surface could be observed behind the main impulse accompanying with the wave height decrease as the wave propagates. This could be found in some papers (Grilli and Svendsen, 1991; Grilli et al., 1994; Hsiao and Lin, 2010) though the focuses of these studies were neither on the generation nor the propagation of solitary waves. Alternative methods were proposed for improving the "stability" of the generated solitary waves (Guizien and Barthélemy, 2002; Malek-Mohammadi and Testik, 2010; Wu et al., 2014). A better "stability" implies that the generated solitary wave can travel a longer distance without an obvious decay. The method proposed in the work of Wu et al. (2014) which just slightly modifies Goring's method seems to have the most effective improvement. However, in that paper the verification was done by using just a potential flow numerical model. Further verification on the method of Wu et al. (2014) was carried out by Farhadi et al. (2016) in which numerical simulations with the incompressible smooth particle hydrodynamics model (ISPH) was employed and the viscosity of the water was considered.

For showing how the method of Wu et al. (2014) works in a real wave flume, we conduct several physical tests in the wave flume at Tainan Hydraulics Laboratory, National Chung Kung University, Taiwan (THL, NCKU). The observed wave heights are systematically smaller than expected. During the experiment, we found that the wave paddle fits the flume imperfectly and water leaks from the gaps during motion of the wave paddle. This is presumed as the reason why the observed wave heights are systematically smaller than the expected and then this is verified by using FLOW 3D®, a commercial software for free surface viscous and turbulent flows, to simulate the process of

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**Table 1**
Formulae and coefficients of the Fenton's ninth order solitary wave solution.

| Order $i$ | $\eta_i$ | $K_i$ | $C_i$ |
|---|---|---|---|
| 1 | $S^2$ | 1.000000 | 1.000000 |
| 2 | $-0.75S^2 + 0.75S^4$ | -0.625000 | -0.050000 |
| 3 | $0.625S^2 - 1.8875S^4 + 1.2625S^6$ | 0.554688 | -0.042857 |
| 4 | $-1.36817S^2 + 3.88033S^4 - 4.68304S^6 + 2.17088S^8$ | -0.561535 | -0.034286 |
| 5 | $1.86057S^2 - 7.45136S^4 + 12.7637S^6 - 11.4199S^8$ $+4.24687S^{10}$ | 0.567095 | -0.031520 |
| 6 | $-2.57413S^2 + 13.2856S^4 - 31.1191S^6 + 40.1068S^8$ $-28.4272S^{10} + 8.728S^{12}$ | -0.602969 | -0.029278 |
| 7 | $3.4572S^2 - 22.782S^4 + 68.258S^6 - 116.974S^8$ $+120.49S^{10} - 71.057S^{12} + 18.608S^{14}$ | 0.624914 | -0.026845 |
| 8 | $-4.6849S^2 + 37.67S^4 - 139.28S^6 + 301.442S^8S^{12}$ $-411.416S^{10} + 355.069S^{12} - 180.212S^{14} + 41.412S^{16}$ | -0.670850 | -0.030263 |
| 9 | $6.191S^2 - 60.57S^4 + 269.84S^6 - 712.125S^8$ $+1217.98S^{10} - 1384.37S^{12} + 1023.07S^{14}$ $-450.29S^{16}+90.279S^{18}$ | 0.700371 | -0.021935 |

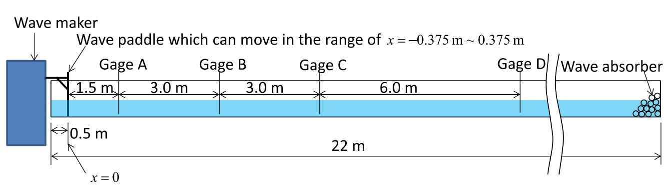


**Fig. 1.** Experiment setup.

**Table 2**
The list of experimental conditions.

| Case | Wave generation method | Still water depth (cm) | Target wave height (cm) | Stroke of the wave paddle (cm) | Maximum speed of the paddle (m/s) | Re (water at 24 °C) |
|---|---|---|---|---|---|---|
| 1 | Goring | 40 | 20 | 65.32 | 0.8086 | $2.886 \times 10^5$ |
| 2 | Goring | 40 | 14 | 54.65 | 0.5966 | $1.782 \times 10^5$ |
| 3 | Goring | 40 | 8 | 41.31 | 0.3615 | $8.161 \times 10^4$ |
| 4 | Modified | 40 | 20 | 71.62 | 0.8023 | $3.140 \times 10^5$ |
| 5 | Modified | 40 | 14 | 59.62 | 0.5947 | $1.937 \times 10^5$ |
| 6 | Modified | 40 | 8 | 43.91 | 0.3613 | $8.668 \times 10^4$ |

solitary wave generation under this condition.

## 2. Goring's solitary wave generation method and its modification

By assuming the average horizontal water particle velocity adjacent to the wave paddle, $\bar{u}$, equals the wave paddle velocity, Goring (1978) derived a formula to determine the wave paddle trajectory during the solitary wave generating procedure

$$\frac{d\xi}{dt} = \bar{u}(\xi, t) = \frac{C\eta|_{x=\xi}}{h + \eta|_{x=\xi}} \tag{1}$$

where $\xi(t)$ is the position of the wave paddle at time $t$, while $t$ is elapsed time since the start of the wave paddle motion, $C$ is the wave celerity or say wave speed, $\eta$ is the free surface displacement, and $h$ is the still water depth. In the dissertation of Goring (1978) the solitary wave solution of Boussinesq (1871) was used to determine the free surface displacement $\eta$ and the wave celerity $C$ for Eq. (1). That is

$$\eta = H\,S^2 \tag{2}$$

where $H$ is the wave height, and

$$S = \operatorname{sech}\left[KX\right] \tag{3}$$

in which $K$ is the boundary outskirt decay coefficient, and

$$X = \xi - Ct - x_0 \tag{4}$$

where $x_0$ is the initial position of the wave crest. Because the solitary wave is generated in a quiescent water flume, $x_0$ must be chosen as a negative value, which means the wave crest is initially out of the domain. Its value is chosen by considering the length of the wave. The boundary outskirt decay coefficient $K$ is determined as

$$K = \sqrt{\frac{3H}{4h^3}} \tag{5}$$

whereas the wave speed is determined as

$$C = \sqrt{g(h + H)} \tag{6}$$

This is a well-known solitary wave generation method proposed by Goring.

By Malek-Mohammadi and Testik (2010) Eq. (1) was challenged while in other papers (Guizien and Barthélemy, 2002; Wu et al., 2014) Eq. (1) was considered acceptable but the way of determining $\eta$ and $C$ were suggested to be altered. The Fenton's (1972) ninth order solitary wave solution was preferred for determining $\eta$ and $C$ in the paper of Wu et al. (2014).