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PHASE II: MODELLING OF THE PROPOSED BREAKWATER FOR THE GEORGIAN YACHT CLUB

prepared for

Don Gibson
Commodore
Georgian Yacht Club

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April 2000

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April 18, 2000
Don Gibson
C/O Tom Chambers
Chambers Air Tool Services
262 Mill st.
Kitchener, Ont.
N2M 3R6

Dear Mr. Gibson:

Re: *Phase II: Modelling of the Proposed Breakwater for the Georgian Yacht Club*

We are pleased to present the attached Phase II report of the above noted project. In this phase of the project, a physical model study was conducted to investigate sedimentation and wave attenuation aspects of the proposed breakwater.

Conclusions and Recommendations - It was determined that the installation of the breakwater should lead to no unwanted sedimentation near the opening of the GYC basin. However, it was also found that the wave attenuation abilities of the proposed breakwater are as good as expected. With this in mind, it is recommended that the GYC look into the wave attenuation abilities of the breakwater in greater depth before proceeding with this plan.

We are pleased to have been of service on this most interesting project. Please contact us if you should have any questions or if further clarification is required. The easiest method of contact is by email to Geoffrey Bell (glsbell@uwaterloo.ca).

Sincerely,
BCD NAUTICAL ENGINEERING

Geoffrey Bell Lawrence Chung Kristian Dorken

Executive Summary

BDC Nautical was retained by the Georgian Yacht Club in September 1999 to conduct an assessment of a proposed breakwater installation. The goals of the project were to determine the effectiveness of the proposal as well as the potential for adverse effects.

Following the Phase I report, a physical modelling approach was adopted in order to conduct a three-dimensional investigation of wave and sedimentary processes within the GYC basin. Space and cost limitations required the model to be built using less than optimal vertical and lateral dimensions, and hence the model was distorted. Such distortions coupled with scale effects inherent in physical modelling made it impossible to satisfy all requirements for a perfectly representative model.

The first goal of the study was to examine the wave attenuation of the breakwater within the harbour. Waves were generated by use of a geared pulley system and measured with data-logging sensors. The results of the wave study showed that current breakwater design as tested will not give the expected wave attenuation performance. However, the results were significantly affected by the boundary conditions and scaling.

Due to the use of a small model, the use of scaled particles was inappropriate for the study of sediment transport. To work around such limitations, a tracer study was performed using dye. A current in the model was generated using a hydraulic pump, to accurately represent prototype conditions. The tracer study was used to characterise the flow field in the model both with and without the breakwater in place. Results from this study show no sizeable impact on sedimentation processes within the GYC basin as a result of implementing the proposed breakwater.

Acknowledgements

BCD Nautical expresses their gratitude to Professors Jonathon Sykes and Nicholas Kouwen, as well as Stefano Normani and Jayson Innes for their help during this project. Also, the completion of this undertaking would not have been possible without the invaluable assistance of Terry Ridgway, Lab Tech Extraordinaire.

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1. Introduction

In September 1999, BCD Nautical Engineering was retained by the Georgian Yacht Club to assist in the resolution of a number of complaints from club members moored in the marina. These complaints were regarding waves entering the harbour in the early hours of the morning and disturbing club members who live in their boats during the summer months.

The Board of Directors of the Georgian Yacht Club has been actively looking for a viable solution to this problem for several years. A consultant was retained to design a breakwater at the mouth of the harbour to address the problem. It was considered that a breakwater might cause shoaling in the already shallow entrance and approach. To investigate this possibility, BCD conducted a physical model study, the results of which are contained within this report.

1.1. Objectives

BCD Nautical Engineering's involvement in this project commenced in September 1999 with a two-phase approach. Phase I was completed in December 1999. The objectives of Phase II of the project are:

1) determination of scaling parameters
2) model construction
3) calibration with respect to existing conditions
4) installation of model of proposed breakwater
5) wave study
6) sediment characterisation

These tasks were completed in March 2000 and this report was prepared to summarise the findings.

1.2. Scope

To assess the potential for siltation with the construction of the breakwater and the effectiveness of that breakwater, BCD Nautical conducted a scale model study of the GYC basin entrance and the surrounding area. While it may be possible to model the situation mathematically, these techniques are still unproven and difficult to implement. As well, they generally are not accurate in describing boundary layer problems, of which this is one.

This study consisted of the design and construction of a physical model of the situation, which required a study of applicable modelling techniques and theory. This model was then calibrated and tested, and the collected data was analysed to answer the objective questions.

One activity that would ideally have been included in the project, but was not feasible due to time and budgetary restraints, is a wave characterisation study.

2. Modelling Approach and Construction

Based on the findings of the Environmental Assessment conducted in the fall of 1999 [BCD, 1999], a model was constructed of the GYC basin opening and the surrounding area. For a complete description of the problem and its repercussions, please refer to Section 2 of the Phase I Report [BCD, 1999].

2.1. Scale Selection

To determine what scale would be feasible to be used within the flume available for the study, drawings of the area to be modelled were superimposed at several scales on an outline of the flume. Considering that some space is required between the modelled coast and the flume's edge in which to generate the waves, it was decided that the largest the model could be without impeding the wave generation is a scale of 1:100 (model:prototype)

2.2. Geometric Dissimilarity

Unfortunately, at a 1:100 scale, the model would not allow adequately sized waves for analysis. At this scale, the appropriately scaled waves would only be 4.5 mm tall[1], which would not allow for accurate measurement. As a result, it was decided that geometric dissimilarity would have to be introduced, in the form of vertical elongation. This is possible due to the shallowness of the area surrounding the basin – the greatest depth in the prototype is only about 6.0m which translates into about 60mm in the model. Since the height of the flume is about 400 mm, a perfectly geometrically scaled model would not utilise the

[1] Waves are estimated to be up to 0.45m in the prototype; 0.45m/100 = 0.0045m = 4.5mm

entire height of the flume.

Allowing for 50 mm of freeboard in the flume, there is 350 mm of vertical space available for the model to occupy. This allows for a maximum vertical:horizontal scale of about 5.8:1. In order to simplify calculations, a ratio of 5:1 was adopted, an exaggeration that will yield properly scaled waves of 24 mm.

The effect this exaggeration will have on the model should be small. In testing for breakwater performance, the waves of interest are surficial only, and do not interact with the bottom. As a result, in this testing programme the movement of the bottom layer of water should approach zero, so that the bottom slope should not be significant. In testing for sedimentation, there is precedent that suggests that vertical exaggeration can be present in an effective model (eg. Hughes, 1993). Also, it had been acknowledged that the model likely will not be able to provide reliable quantitative results due to its scale and the resources available, so it was decided to tolerate slight inaccuracies.

2.3. Scale Effects

An effect which can have a significant impact in a model, and which must be dealt with, is the lack of scaling of the fluid viscosity. This will be noticed in the water-breakwater interaction; with the small pores in the model breakwater, viscous forces will become more predominant than in reality, and wave transmission and reflection from the model breakwater will be proportionally less than could be expected in the prototype. To overcome this, the armour stone on the model will have to be sized differently than is suggested by geometric scaling. To determine this departure from geometric similitude, we used the relationship described by Hughes [Hughes, 1993]

$$N_L = KN_D$$

Where K is a factor greater than one that describes the increase in size of the stone, N_L is the recommended stone size and N_D is the stone size given by the geometric scaling. K is determined with the following procedure:

$$\frac{H_i}{\Delta L} D_P{}^3 P_p{}^5 = \frac{0.45m}{5.0m} \times (30cm)^3 (0.35)^5 = 12.76$$

Where: H_i = incident wave height
ΔL = average width of the core material section
D_p = effective diameter of prototype core material (cm)
P = Porosity of core material

Referring to the chart in Figure A.1, finding the intersection of this value and the overall scaling factor of 100, this gives a K value of approximately 3.0. Thus, instead of the model armour stone size of (50cm/100 =) 5 mm suggested by the geometric scale, armour stone of 15 mm diameter was dictated for use in the construction of the model breakwater. What was used was ¾" (19mm) gravel which was readily available. To compensate, a small amount of smaller (12mm) stone was incorporated into the aggregate mix used to form the breakwater (see Sec. 2.5 for model construction details)

2.4. Laboratory Effects

As for laboratory effects, only two of the three common effects (non-linearity of waves resulting from wave generation, simplifying assumptions, boundary effects) were pronounced. The use of a model vessel towed through the flume to generate waves takes care of the non-linearity associated with the wave generation. While this method lacks the simplicity of a wave board, it has the advantage of accurately recreating the surface wave energy that is present in the prototype.

As mentioned earlier, some simplifying assumptions must be made in order to make the model feasible given the time and budget constraints. Of course, care was taken to ensure that as few concessions as possible were made so as to generate as accurate a model as possible given the resources available. Nonetheless, it is realized that the resulting model will be only an approximation, useful more for qualitative results than for quantitative ones.

One effect which did exist and which did impact the results is that of boundary effects. It is expected that the waves entering the modelled basin mouth will be reflected by the flume wall that covers what would be the rest of the GYC basin. In the actual basin, these waves would be absorbed by the boats and docks within. This flume interaction created a chaotic set of waves that had to be damped in order to be able to gather some interpretable wave height data. This was accomplished by placing some loose fabric against the wall of the flume to absorb rather than reflect most of the wave energy striking the wall.

2.5. Model Construction

Depth data obtained from the Department of Fisheries and Oceans was input into graphing software, which then interpolated a fine mesh of depths (Figure A.2). Slices were taken through this model, which were transferred onto plywood and cut out. These plywood pieces were affixed to the bottom of the flume and joined with strips of flexible wood to create a skeleton (Figures A.4, A.5). Fabric was then impregnated with fibreglass resin and stretched over this skeleton, forming a shell which would isolate the water beneath the modelled lakebed from flow in the area of interest.

To form the basin mouth, more detail was desired than could be achieved with the above method, so concrete was used to reproduce this area. Another area where the fiberglass technique was thought to be inadequate is the breakwater itself, as well as the breakwater enclosing the Owen Sound Marina. For these structures, the porosity and roughness were considered to be important, so these were reproduced using scaled stone. However, at the extreme slope brought about by the vertical exaggeration, the stone would not support itself without slumping. To overcome this, a concrete was mixed using only cement and ¾″ stone (with some ½″ stone), so that the result was essentially stone with a thin layer of cement on the stone surface holding it together. This was poured into forms, resulting in an accurately shaped and stable breakwater structure. A picture of the finished model appears as Figure A.6.

3. Modelling Wave Attenuation

Once the model was built, the first objective was to measure the performance of the proposed breakwater. Two main challenges were encountered while attempting to determine its performance: wave generation and data collection.

3.1. Wave Characterisation

In this study, the waves of concern are the waves created by the wakes of fishing boats navigating up the sound. These are surface waves, which have their energy concentrated in the top portion of the water column.

For the wake waves relevant to the study, estimations of key wave parameters required in design calculations are presented in Table 3.1 below.

Parameter	**Symbol**	**Units**	**Model**	**Prototype**
Period	T	S	0.15 s	1.5 – 2 s
Wave Height	H_I	m	2.25 cm	0.45 m
Wave length (crest to crest)	L	m	15 cm	3 m
Wave steepness	H_i/L	-	0.15	0.15
Wave Parameter	H_i/gT^2	-	0.0115 – 0.0204	0.0115 – 0.0204

Table 3.1: Estimations of wave characteristics of problem waves

3.2. Wave Generation

The generation of properly scaled waves was necessary in order to determine the effectiveness of the proposed breakwater. Waves were generated by towing a scaled boat with a pulley system, as shown in Figure B.1. The pulley system consisted of a frame with a bicycle gear cluster, 7m of bicycle chain and a turnbuckle to adjust the friction in the system. The turnbuckle and gear cluster were used in combination to adjust the speed of the boat such that it would produce waves of the proper height (20-30 mm model dimensions; equivalent to 0.40-0.60m ≈ 1 ½′ to 2′ - prototype dimensions).

3.3. Data Collection

Data collection was a necessary step in the evaluation of the breakwater. This proved difficult to implement, however. The first attempt at electronic data acquisition involved two parallel electrodes partially immersed in the water. The intent was to pass a current through the electrodes and the voltage drop across them would be proportional to the water height. The two main difficulties with this approach were the fact the electrodes were being corroded and more importantly the electrodes were behaving as a capacitor rather than a resistor.

The second approach was to use linearly varying differential transducers (LVDTs) with a buoyant float attached to the piston, as shown in Figure B.2. LVDTs consist of a conductive piston that slides freely within a tube. A current is passed through the tube, and the output is proportional to the contact length of the piston within the shaft. These were calibrated with the aid of measuring tape and dye. The initial water level was measured on the tape and dye was added to the tape. The maximum wave height during a simulation was recorded by observing the length of tape where the dye had been washed off by the passing wake waves.

3.4. Wave Results

Several simulations were conducted with the existing conditions in place and with the proposed breakwater installed. The results are summarised in Figures B.3 and B.4, while the wave sensor output data can be found in Appendix D along with summary tables. The average wave attenuation factor (WAF) resulting from existing shoreline features was found to be 22.4% within the harbour, compared to 31.6% after the model breakwater was installed. At first glance, this indicates that the breakwater was poorly designed. This may be the case. However, the size of the model and the boundary location within the harbour also affected the results. It is also possible that the actual wave approach angle was not accurately reproduced due to the model geometry and space limitations. It was observed that the first wave brought a relatively large volume of water into the GYC basin, which was amplified as the basin mouth constricted approaching the inner basins. This effect would be reduced within the basin once the wave had entered into the wider basin area. However, it could not be measured, as the model boundary did not extend far enough in the basin.

A Monte Carlo approach to the data interpretation, in which the random nature of physical models decreases with an increasing number of trials, reveals that the WAF was fairly stable for both cases, as seen in figures 4.3 and 4.4. It would have been desirable to conduct more simulations of each case, however, there was not sufficient time to accomplish this.

4. Modelling Sedimentary Processes

4.1. Overview

The ultimate goal in modelling sedimentary processes is to understand and to predict changes in bathymetric stability in response to the variety of processes that occur in the coastal environment. The scope of this project addresses the concern of sedimentation associated with the proposed construction of a rubble mound breakwater. Such coastal developments will affect coastal zone processes by: (1) changing the rate and/or characteristics of the sediment supplied to the GYC basin, (2) adjusting the level of wave energy flux to the basin, and (3) directly interfering with coastal sediment transport processes. (Sorensen, 1997)

The purpose of this section on sedimentation is threefold. First, to discuss some principle theories behind the modelling of sedimentary processes. Second, to describe the development and rationale for the approach taken in modelling such processes within the physical model. Third, to report on the results obtained from the physical modelling of sedimentary processes.

4.2. Theory

From a physical point of view, sedimentary processes are the result of fluid/sediment interactions, or more specifically, the response of sediment particles to the forces produced by shoaling waves, tides, coastal currents, and winds. Sedimentary processes are among the most important but least understood aspects of the coastal environment (CCEMS, 1989).

In studying sediment transport, quantifying the total sediment movement under a variety of conditions is the primary objective. When dealing with the seabed, there are two types of transport. *Bed-load* transport refers to those grains sliding, rolling, or moving within several grain diameters of the seabed, and *suspended-load* transport, which involves grains suspended by fluid turbulence.

Physical and numerical modelling are both possible approaches to modelling sedimentary processes. However, the complex geometry of the GYC surroundings and the increased ease of visualization when dealing with a scaled version of the system of concern are such that physical modelling is the preferred approach.

There appear to be two major requirements in proper physical modelling of sedimentary processes: (1) a knowledge of the character of the dominant forces, and (2) an understanding of the dominant response mechanisms of the sediment. This project will address physical modelling of nearshore sedimentary response for the case of a *non-cohesive* material.

In developing a recommended procedure for modelling sedimentary processes, the following are suggested:

1. The model will be undistorted.
2. The nearshore hydrodynamics and relevant sediment parameters will be modelled according to the Froude criterion. In Froude modelling with an undistorted length ratio (L_r), the time ratio (T_r), and velocity ratio (V_r), are scaled according to: $V_r = T_r = \sqrt{L_r}$
3. The scale of the experiment will be sufficiently large that viscous and surface tension effects are negligble. (Dean, 1985)

The scale relationships for any other physical parameter of interest can be determined directly. The fall velocity is a relevant parameter that pertains to suspended sediment transport, and must follow the Froude scaling:

$$w_r = \sqrt{L_r}$$

where w_r is the fall velocity ratio, and L_r is the length ratio. This concept of similarity of trajectories can also be applied to a distorted model.

An additional basis for modelling is that of satisfying the *Shields* criterion which applies to the initiation of sediment motion:

$$(\tau_o)_c = \rho g D(S-1) f_1\left(\frac{U_* D}{v}\right)$$

where $(\tau_o)_c$ is the critical shear stress for incipient motion, ρ is the mass density of the fluid, S is the specific gravity of the particle, U_* is the shear velocity, D is the particle diameter, v is the fluid kinematic viscosity, and g is gravity.

In summary, the proposed requirements for a nearshore movable bed model are: (1) an undistorted Froude model, (2) sediment fall velocity scales as $\sqrt{L_r}$, (3) where possible (D_m>0.08mm), the material should be sand, otherwise light particles with the proper scaled fall velocity should be used. (Dean, 1985)

4.3. Challenges

The generally accepted theories for modelling sedimentary processes, as discussed above, were not in complete agreement with the physical model constructed in the laboratory. These theories recommended an undistorted model; however, the model constructed had no other option except to use a vertically distorted scale. The rationale for using a distorted model is simple. Surface tension forces will become important in physical models where the reduced scale causes very shallow depths in some areas of the model. To overcome this potential problem, many models must employ a distorted vertical scale (Sorensen, 1997).

Light particles with the proper scaled fall velocity was also recommended for use in the model. This principle was not satisfied because field measurement of sediment transport was unavailable. Collecting such data is generally made through the use of both sediment tracers and sediment traps that collect suspended load and bed load material passing the trap, both of which methods are beyond the time and budgetary constraints of this project. Without information pertaining to field transport processes, a scaled fall velocity cannot be calculated and used in the model. Hence, the use of particle tracers in the modelling of sedimentary processes becomes inappropriate.

The dissimilarities between actual model properties and required model lead to '*scale effects*', which is yet another issue that must be fully understood in order to gain a proper understanding of results from physical modelling (Kamphuis, 1985). In this case, the fluid phase properties (such as viscosity) of the model are not scaled down but are the same as in the prototype. In addition, gravity, the driving force for open channel models cannot be scaled down.

Faced with these limitations, the modelling of sedimentary processes at GYC becomes a great challenge. In fact, such investigations have always been highly difficult, as there is no proven method for accurately modelling nearshore sediment transport. The theories discussed in the previous section are merely empirical guidelines. There is no guarantee that adherence to these guidelines will produce a model that truly represents processes in the prototype.

However, while there are often serious scaling problems associated with the investigation of sediment transport processes, some useful basic investigations and model studies for specific locations have been carried out. Some model studies where the bottom geometry is fixed but a granular tracer is used to indicate potential shoaling and scour patterns have been useful (Sorensen, 1997).

4.4. Method

For the purposes of modelling sedimentary transport in this project, a granular tracer was deemed to be infeasible as explained earlier. Instead, a tracer study was performed through the injection of a long-lasting, conservative dye (Rhodamine).

From field observations, coastal currents, however small, constituted the primary mechanism responsible for sediment transport. The first step in modelling sediment transport involved the generation of coastal currents to accurately reflect prototype conditions. Figure C.1, in Appendix C, illustrates what was done to try to accomplish this task. A single hydraulic pump was used to draw the water from a distribution header in the north end of the model flume, feeding it back into a distribution header in the south end of the flume. This effectively causes the water in the model to flow north across the GYC basin in a direction that exits the sound from South to North.

The pumping rate was adjusted to 18 gal/min to obtain an average flow velocity of 1cm/s, as measured across the section that intersects the GYC's basin. This velocity was used to maintain Froude similarity with the prototype, which was estimated to have an average flow velocity equal to 0.1m/s across the same section.

Having coastal currents modelled, the next step involved the injection of dye at various points in a grid pattern in the vicinity of the GYC basin. At each point of injection, the vector (direction and velocity) describing the movement of dye was recorded. Velocity measurements were recorded qualitatively from a scale of zero to three, with zero being stagnant (no flow), and three being high.

4.5. Results

In order to gain an understanding of the effects the proposed breakwater will have on coastal sedimentary processes, the tracer study was performed without and then with the model breakwater in place. Results from both situations of this study are illustrated in Figures C.2 and C.3 in Appendix C.

Both cases show two distinct zones of flow (as shown by the larger arrows in Figures C.2 and C.3). As well, these zones are essentially the same in shape and scale in both situations, indicating that the addition of a breakwater has little influence on the two major zones of flow. Moreover, there exists a zone of stagnation (no flow) surrounding the GYC basin, with and without the breakwater in place.

These results suggest that the construction of the proposed breakwater will not alter sedimentary processes within the GYC basin. With stagnant zones located within and in front of the GYC basin, the model does not predict shoaling to occur in the prototype, which agrees with observations. That the addition of the breakwater in the model did not significantly alter this flow regime suggests that this situation will not change. Ultimately, according to physical modelling results, there is little risk of sedimentation and thus the need for dredging activity within the GYC basin. The construction of the proposed breakwater will not influence sedimentation processes.

5. Conclusions

Physical modelling of open water systems is generally considered to be extremely difficult; which proved to be the case in this situation.

Considerable attention was given to correctly build a Froude model. In spite of this care, the model was found to be too small. The boundary effects also played a large role in affecting the results. This is seen in both the wave and sedimentary study.

In the case of waves, the inner harbour boundary greatly affected the results. It decreased the apparent wave attenuation within the GYC basin.

The study of sedimentary processes demonstrated that stagnant flow fields exist within the GYC basin under existing conditions. The installation of the proposed breakwater has negligible impact on current flow fields. Hence, it is predicted that subsequent to installing a breakwater, there would be little or no risk of increased sedimentation in the harbour mouth of the GYC.

6. Recommendations

Based on the study conducted, BCD Nautical strongly recommends that further investigation is required prior to the installation of the breakwater. For subsequent modelling investigations, the following is suggested:

- A more in depth field investigation is required to accurately calibrate the model.
- A larger scale model to reduce scaling effects.
- Boundaries should be placed further away from areas of interest and include the entire GYC basin.
- Wave absorbers should be placed at the appropriate boundaries to minimize reflection of incident waves.
- For the modelling of sediment transport, an undistorted model should be used.
- Scaled particles would better represent the prototype and should be used rather than dye.

While it is not recommended, if the Georgian Yacht Club decides to implement the breakwater solely on this report, the following should be considered:

- The current breakwater design may not sufficiently attenuate waves, and hence changes to the design may be required.

If on the other hand, a breakwater is not deemed suitable by the GYC, the alternatives described within the Phase I report may be revisited and more carefully evaluated. The other alternatives considered were:

- do nothing
- speed control
- other breakwaters – floating and vertical

7. References

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Appendix A – Model Construction

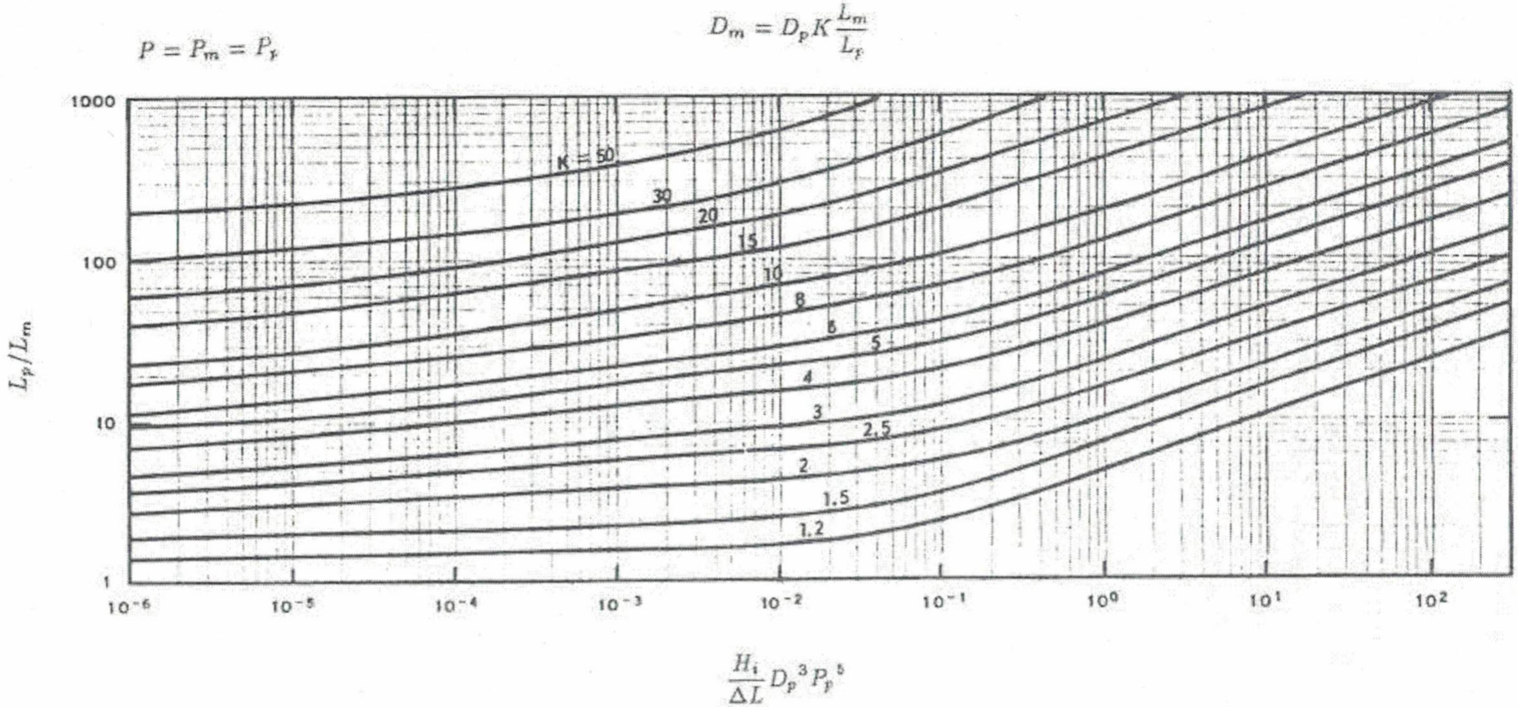


Figure A..1: Le Méhauté's nomograph

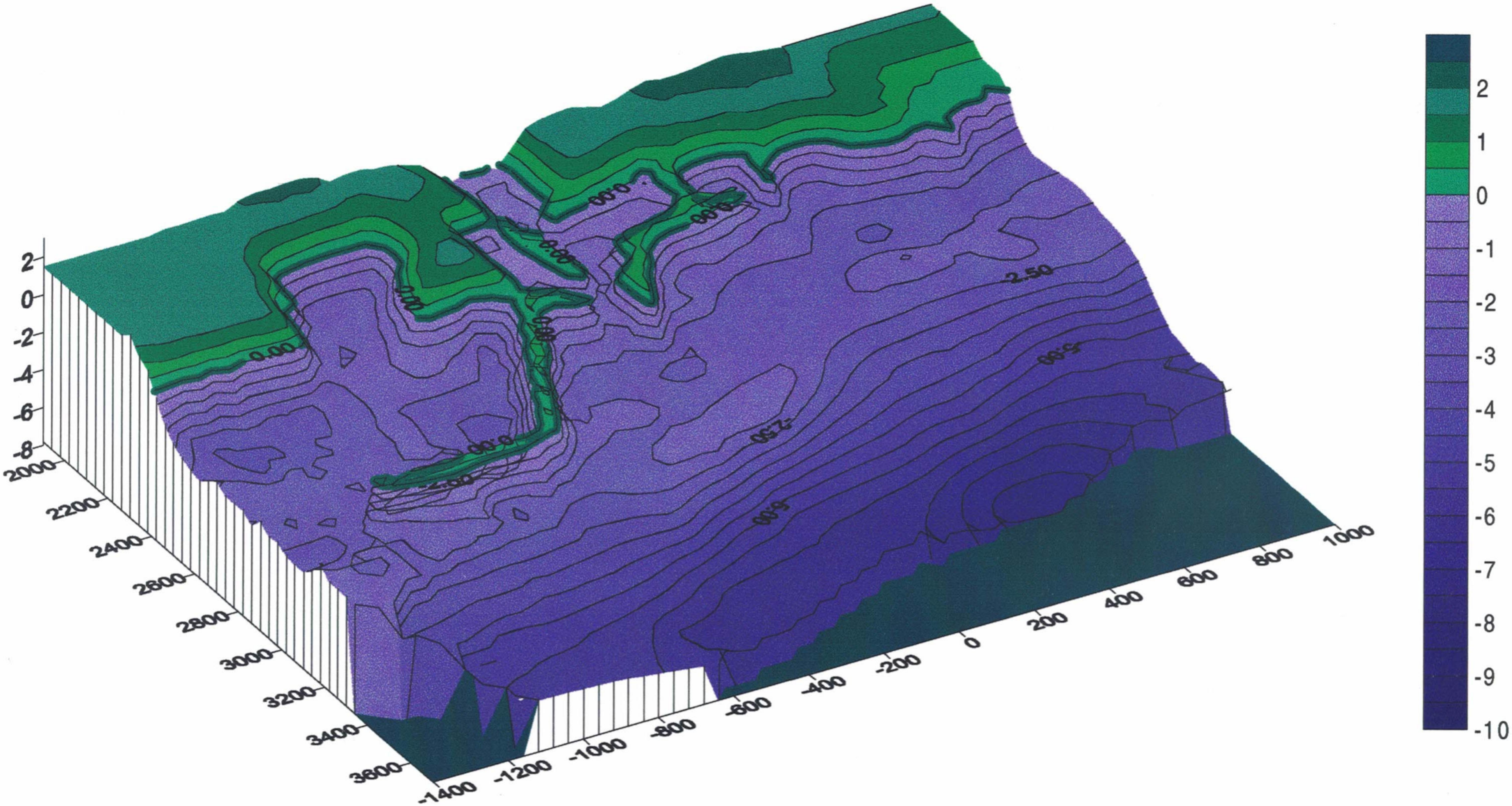


Figure A.2: Image of model using depth grid interpolated by Surfer

Figure A.3: Original flume before enlargement

Figure A.4: Enlarged flume with vertical cross-section in place

Figure A.5: Model ready for fibreglass skin

Figure A.6: Finished model

Appendix B – Wave Modelling Procedure and Results

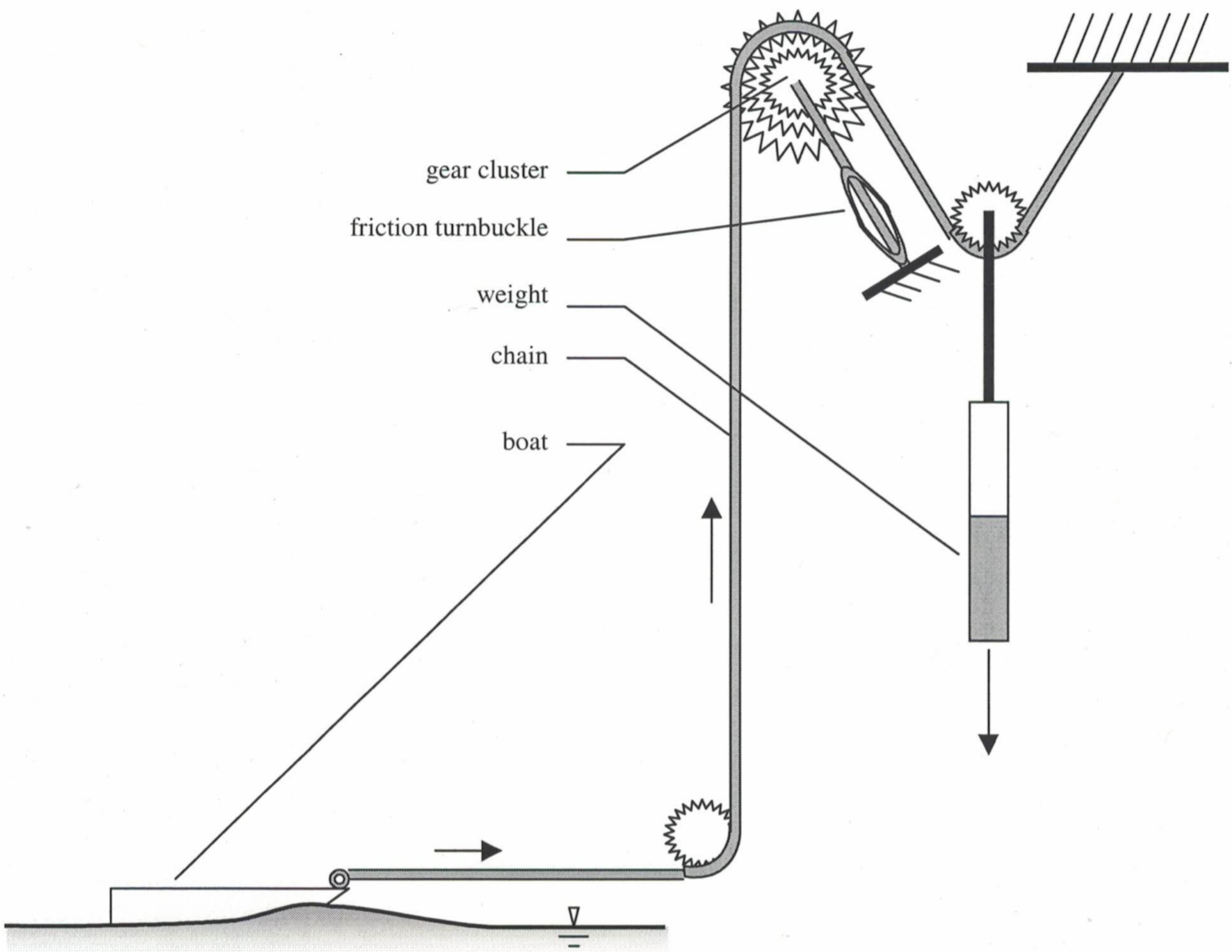


Figure B.1: Wave generation apparatus

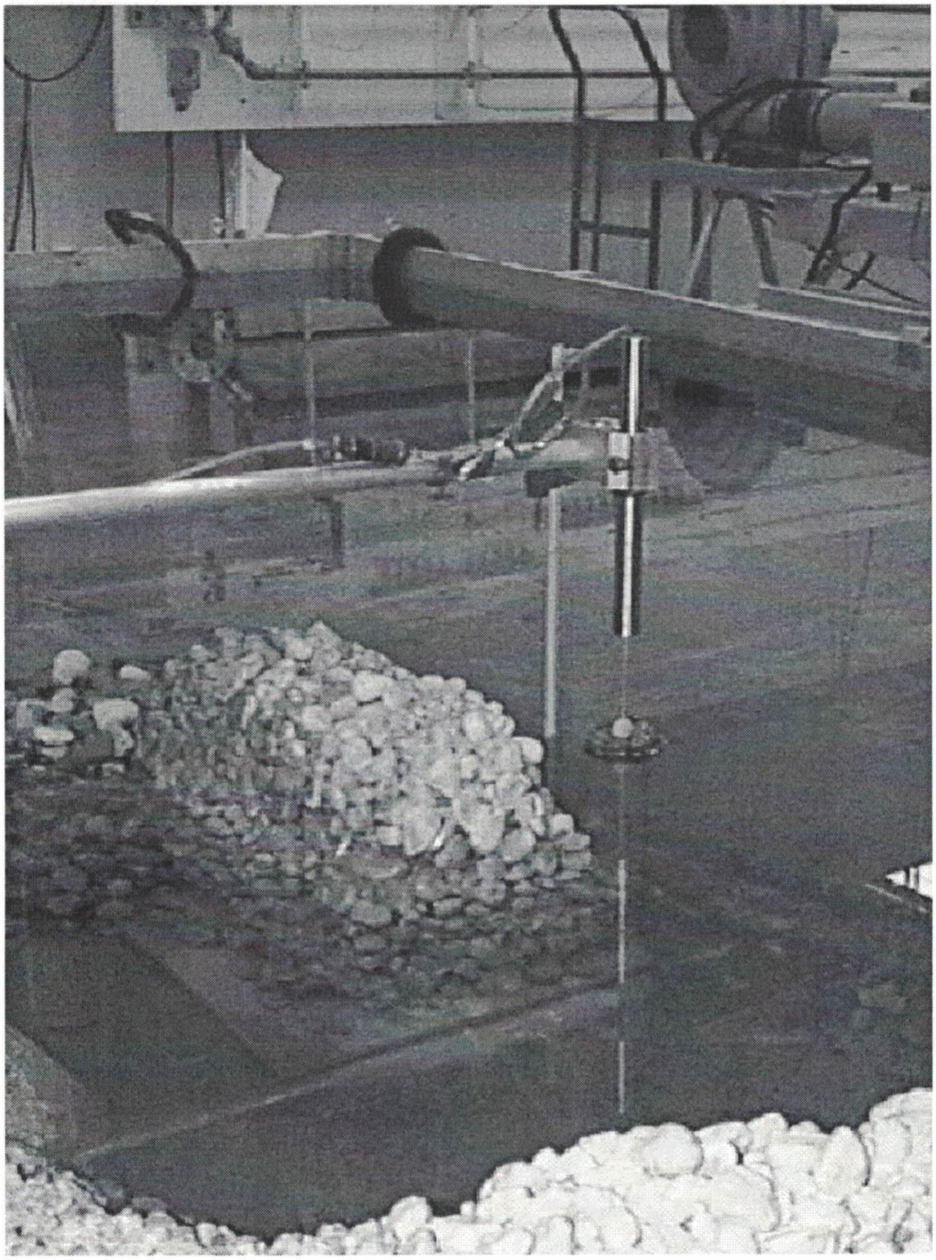


Figure B.2: LVDT used for measuring waves

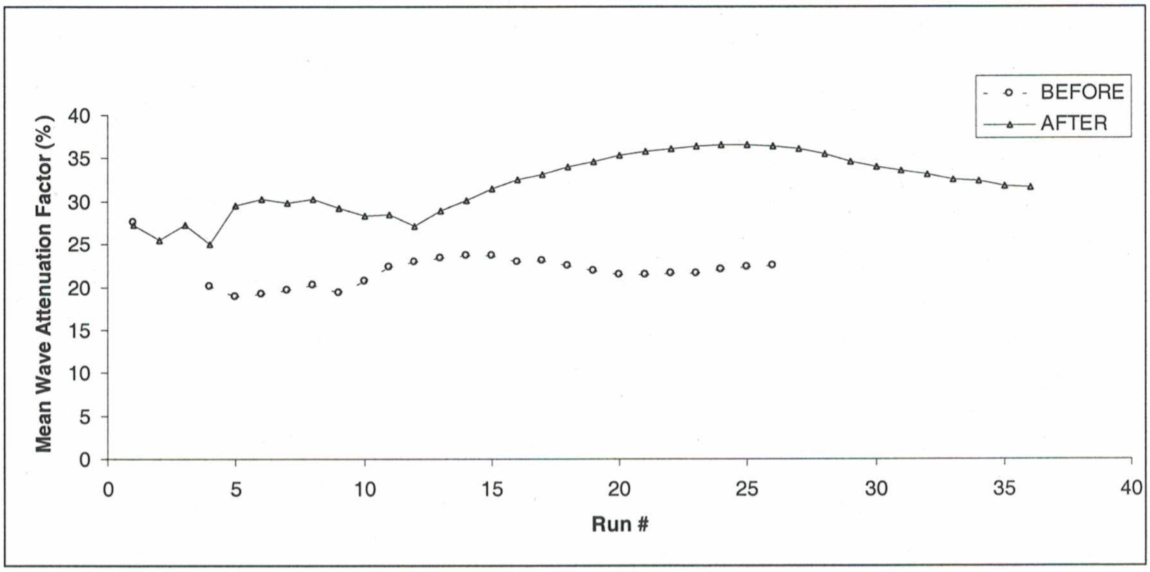


Figure B.3: Running Average of Breakwater Effectiveness for WAF Prediction

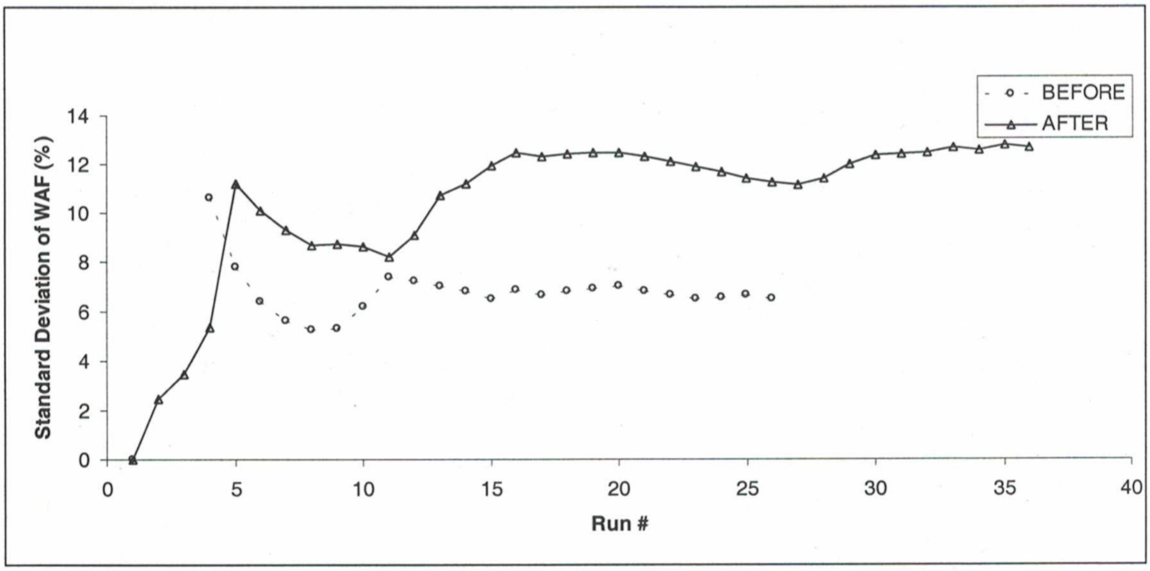


Figure 3.4: Running Standard Deviation of Breakwater Effectiveness for WAF Prediction

Appendix C – Sediment Modelling Results

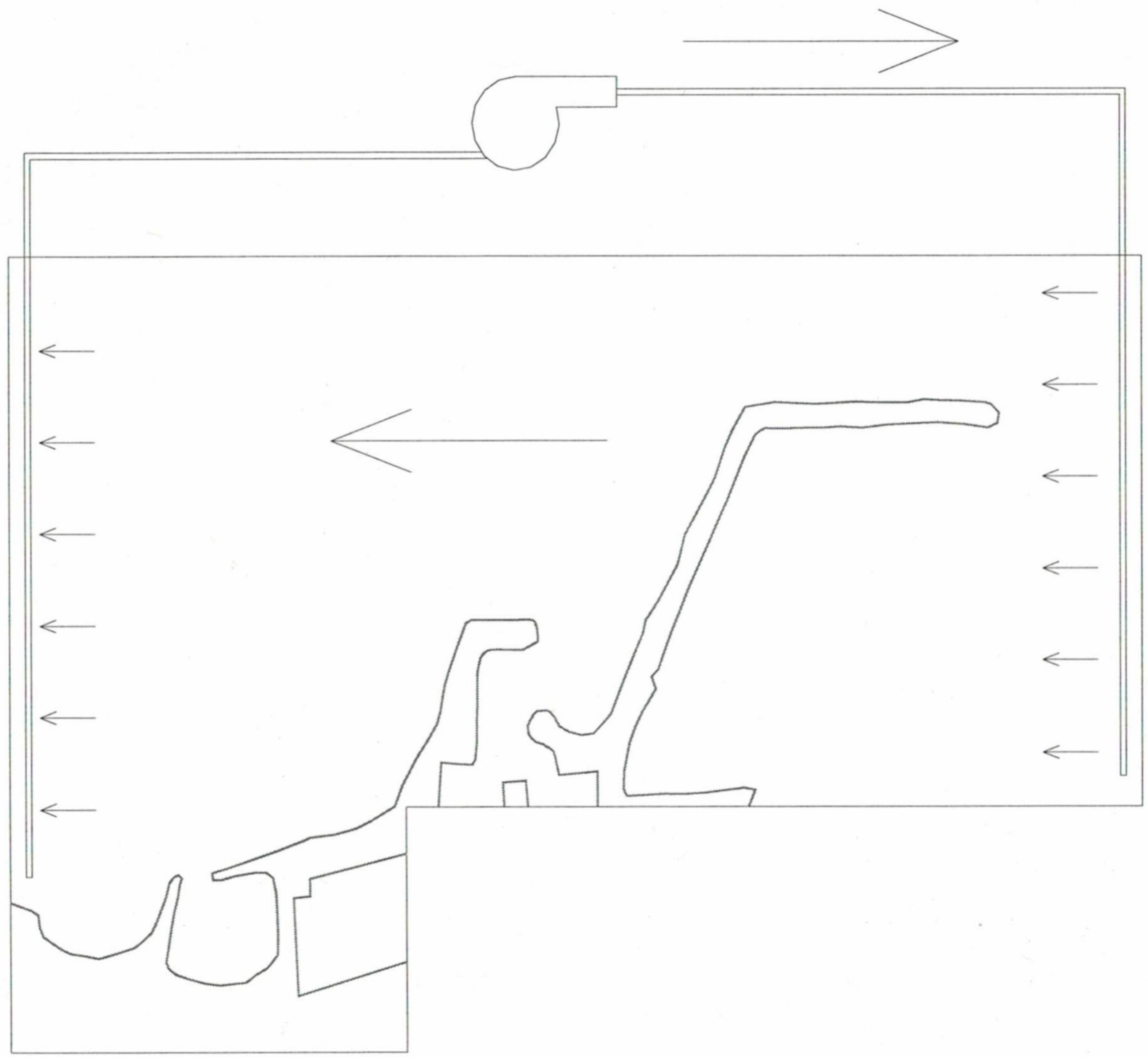


Figure C.1: Schematic of Current Generation System

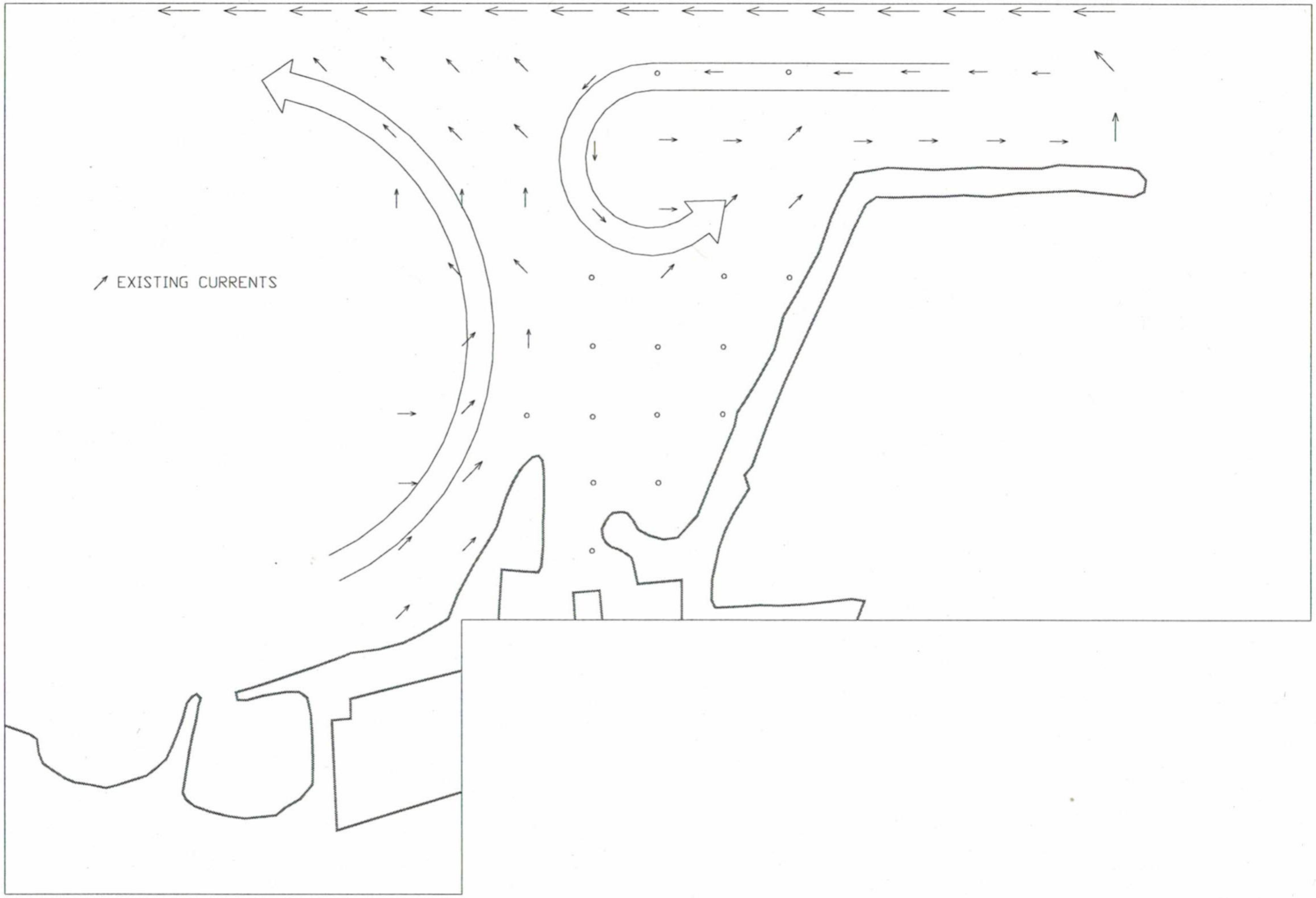


Figure C.2: Current regime before installation of breakwater

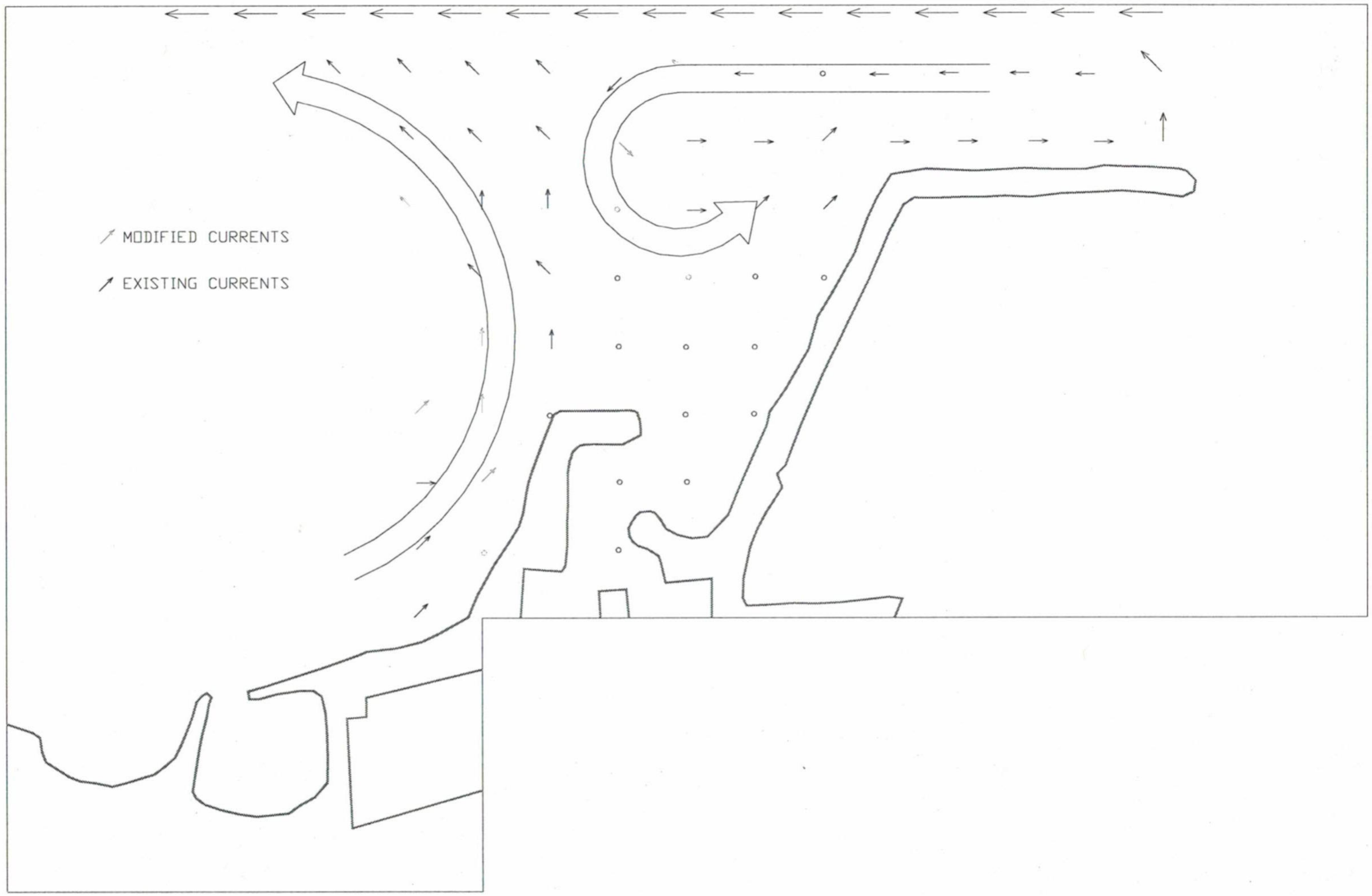
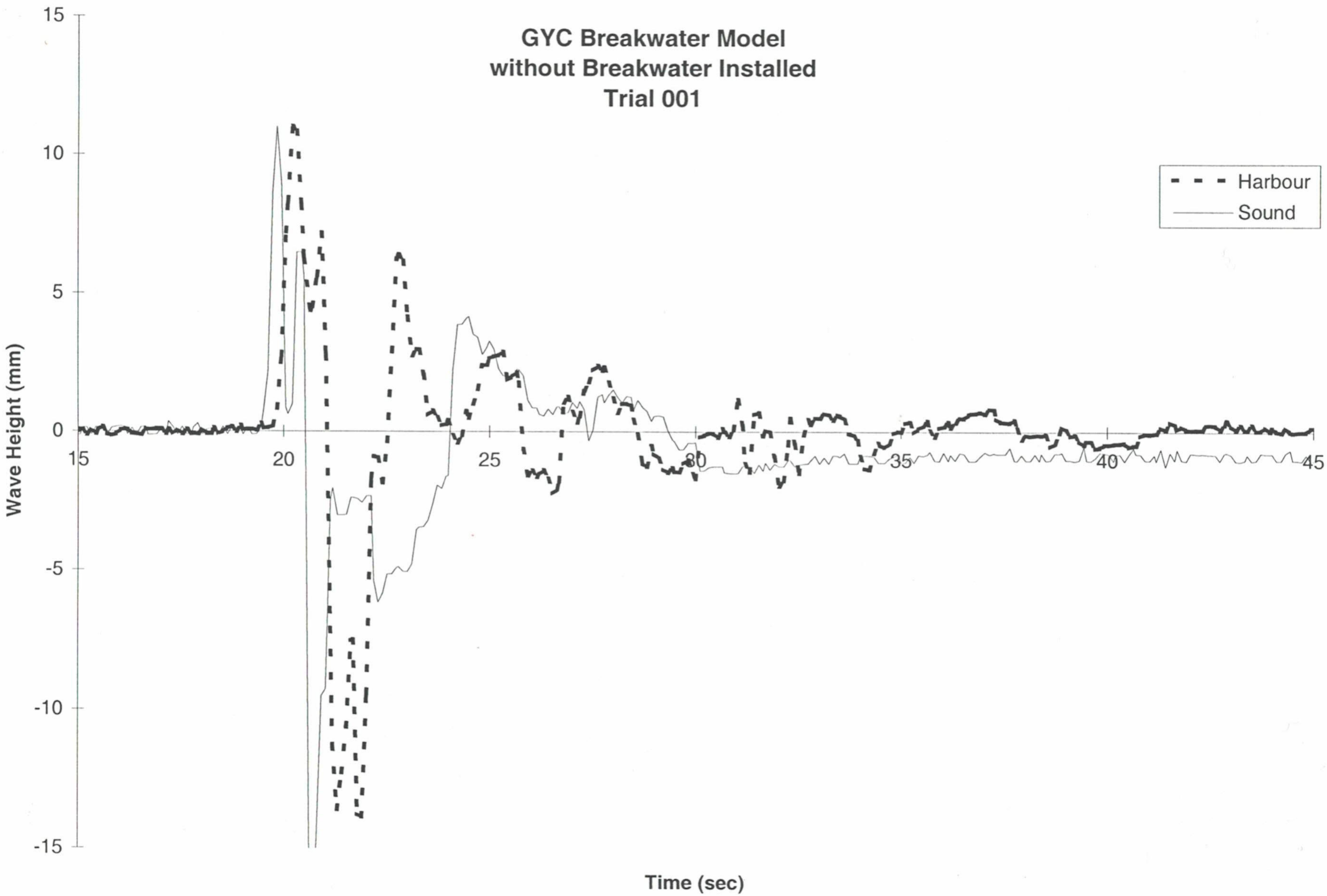
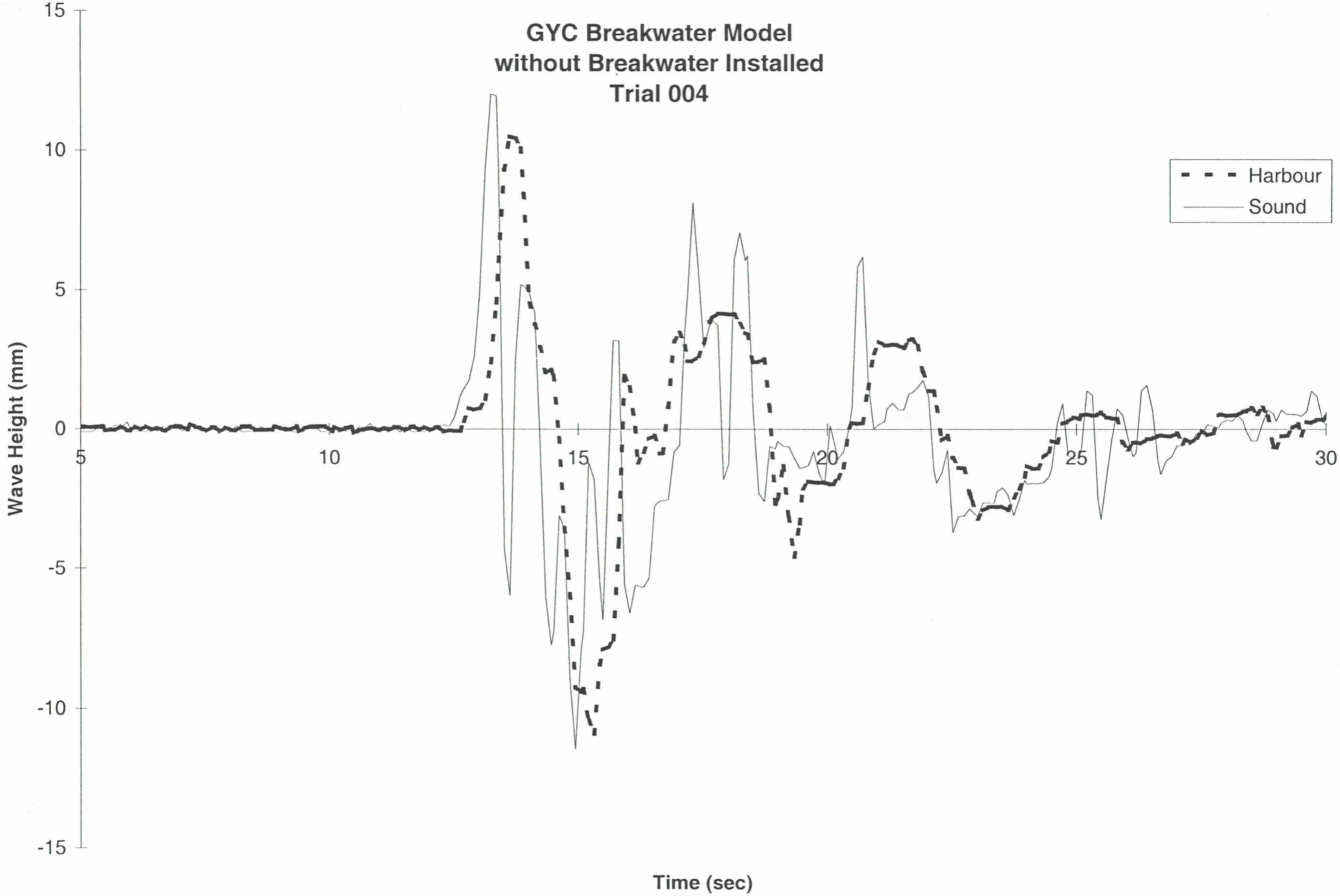
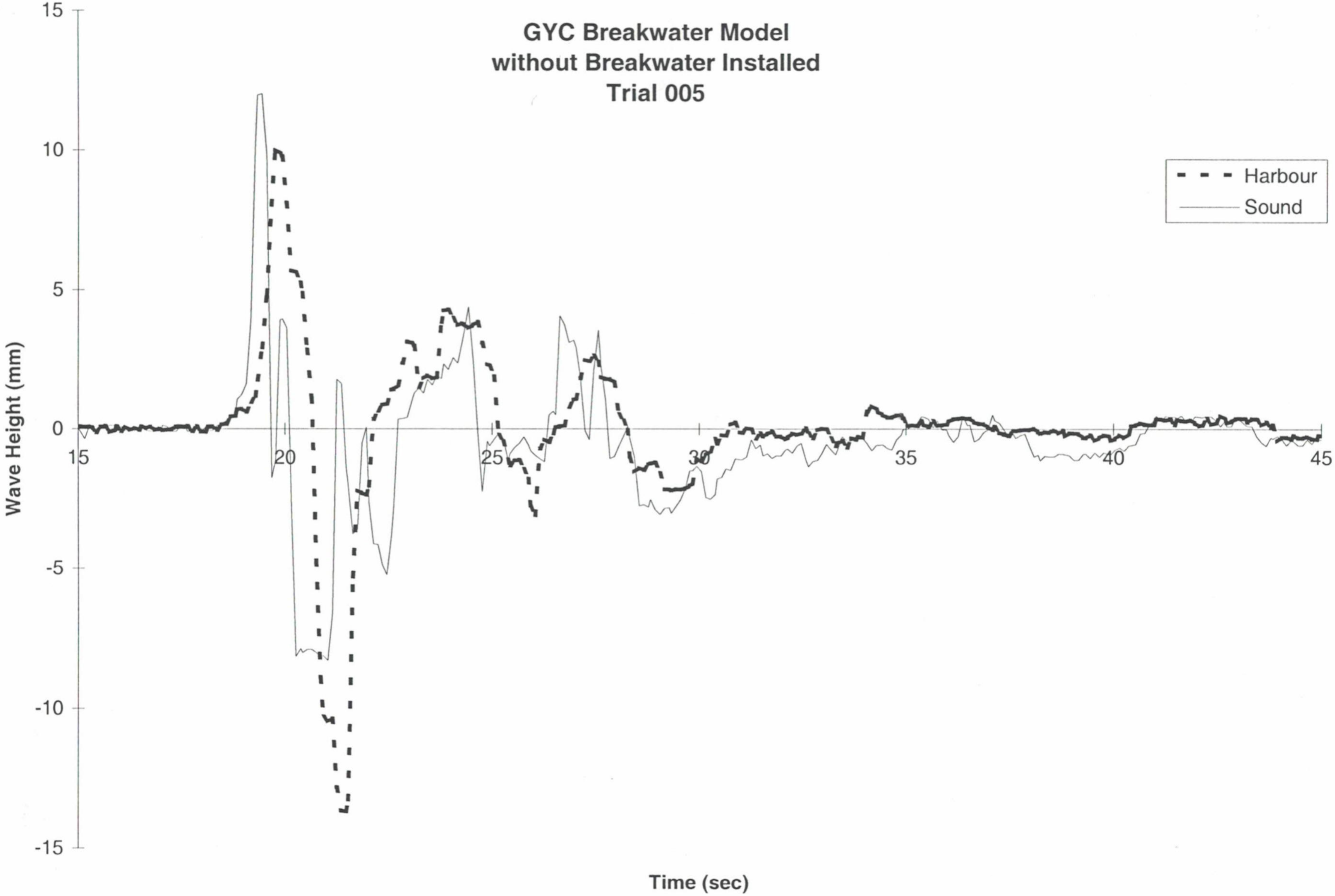


Figure C.3: Current regime after installation of breakwater

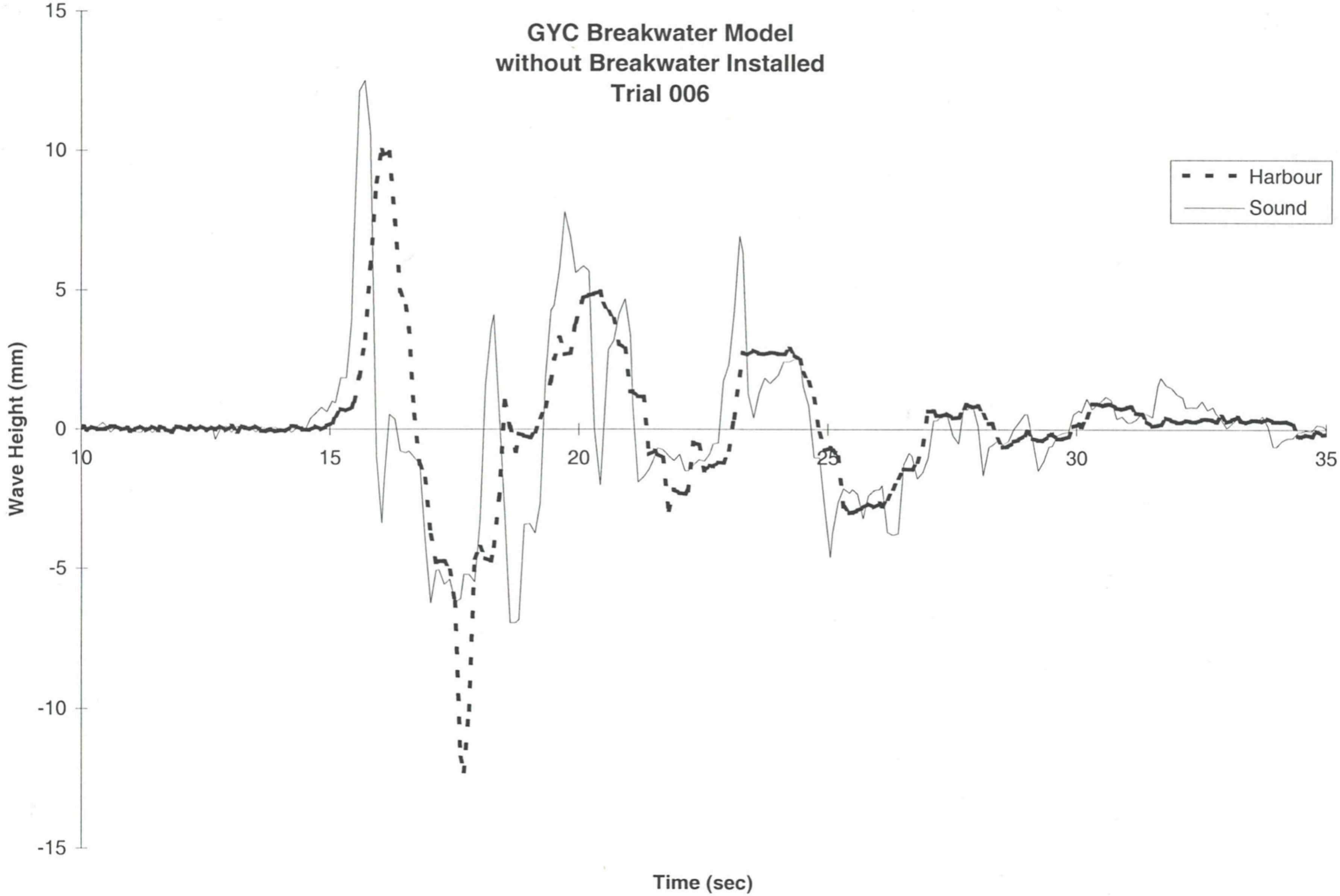
Appendix D – Wave Data


GYC Breakwater Model
without Breakwater Installed
Trial 001
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
15
20
25
30
35
40
45

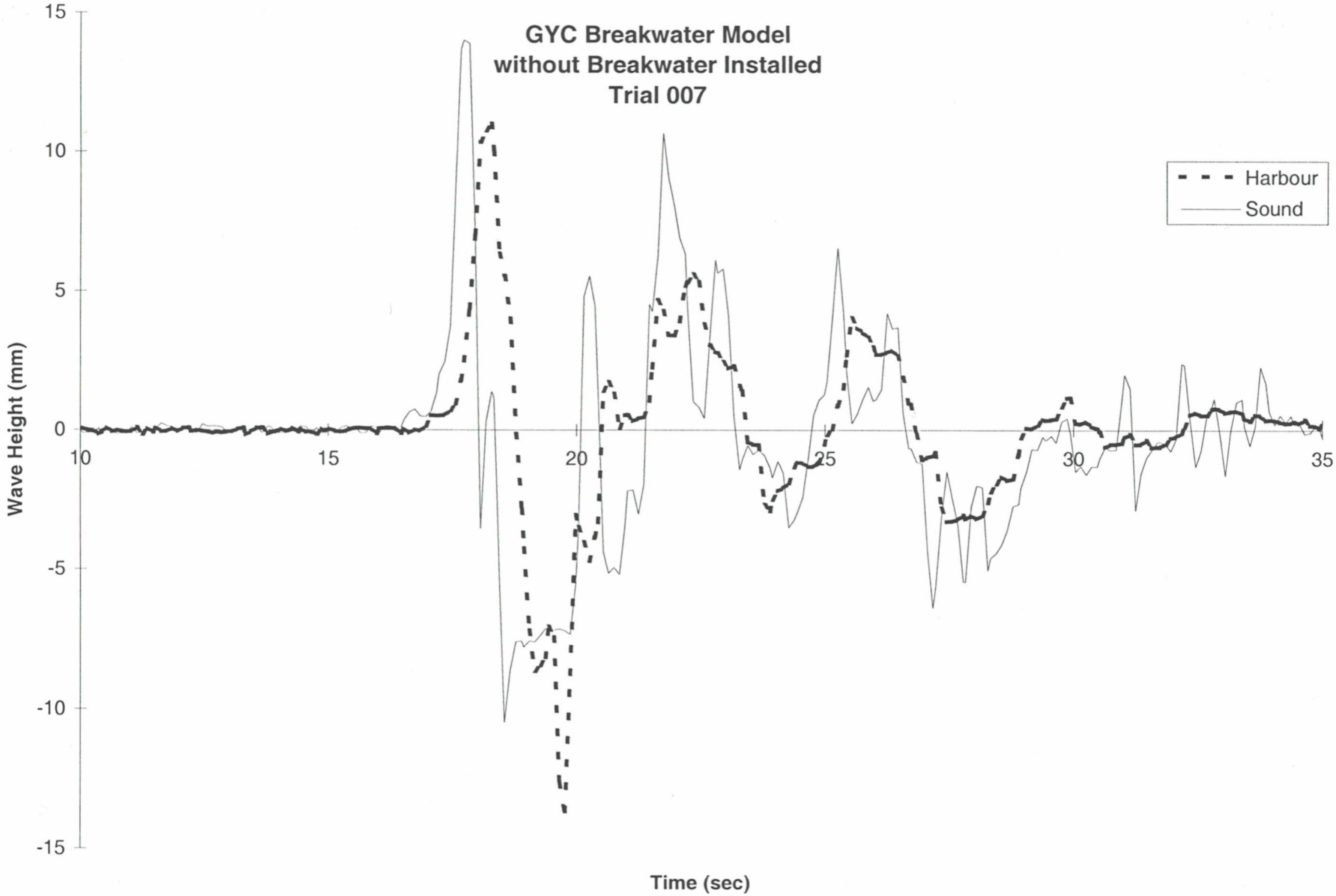

GYC Breakwater Model
without Breakwater Installed
Trial 004
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30

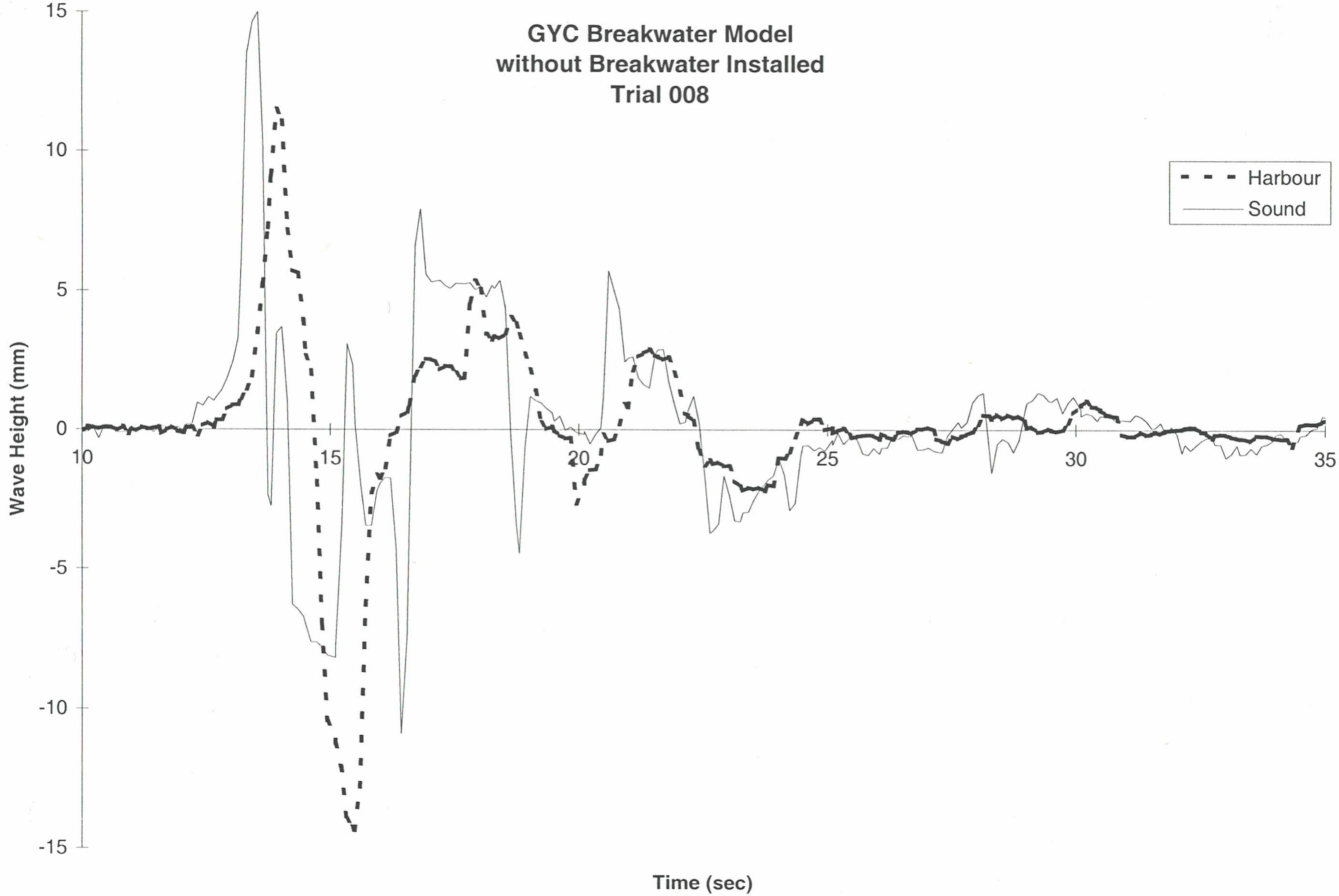


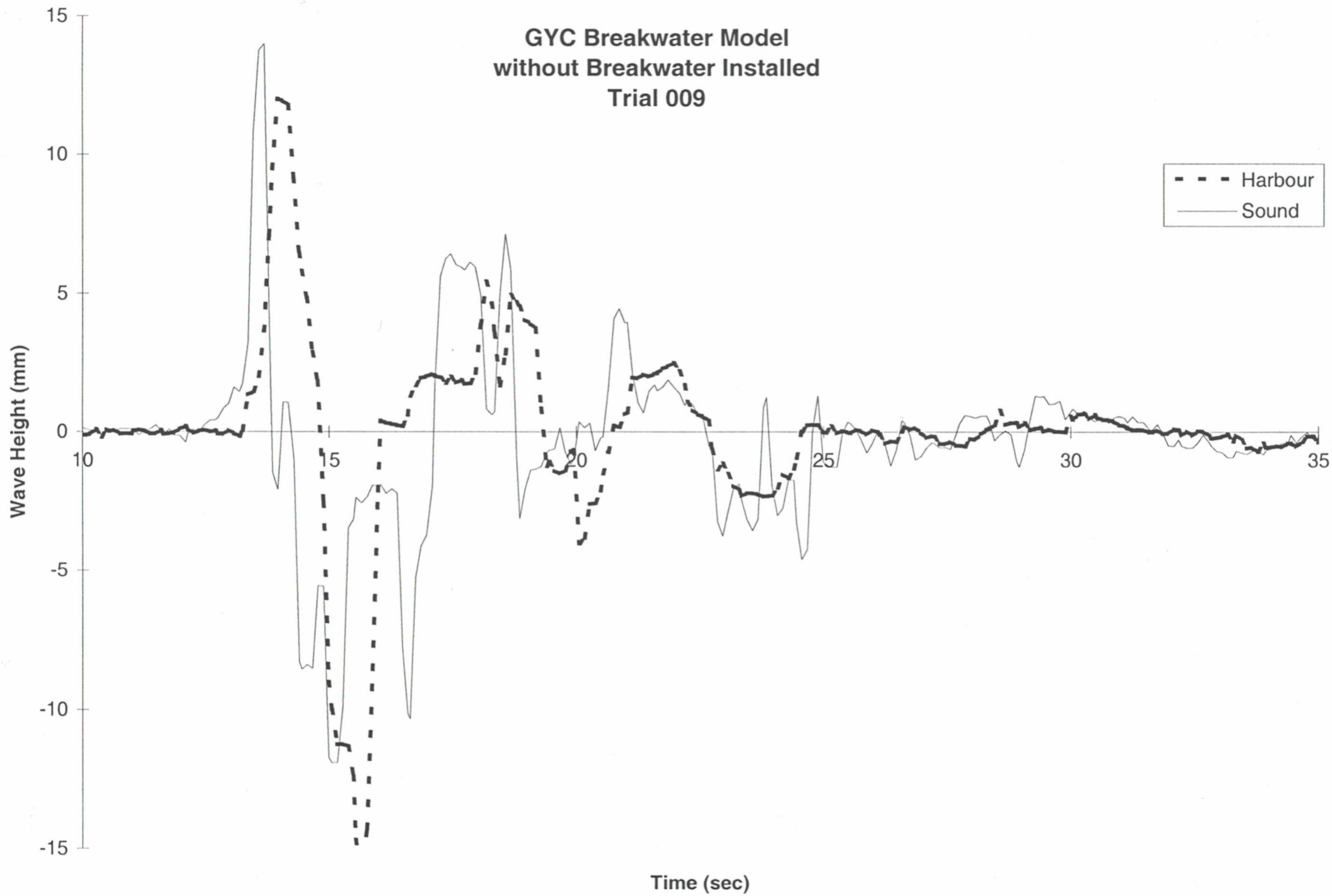
GYC Breakwater Model
without Breakwater Installed
Trial 005
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
15
20
25
30
35
40
45



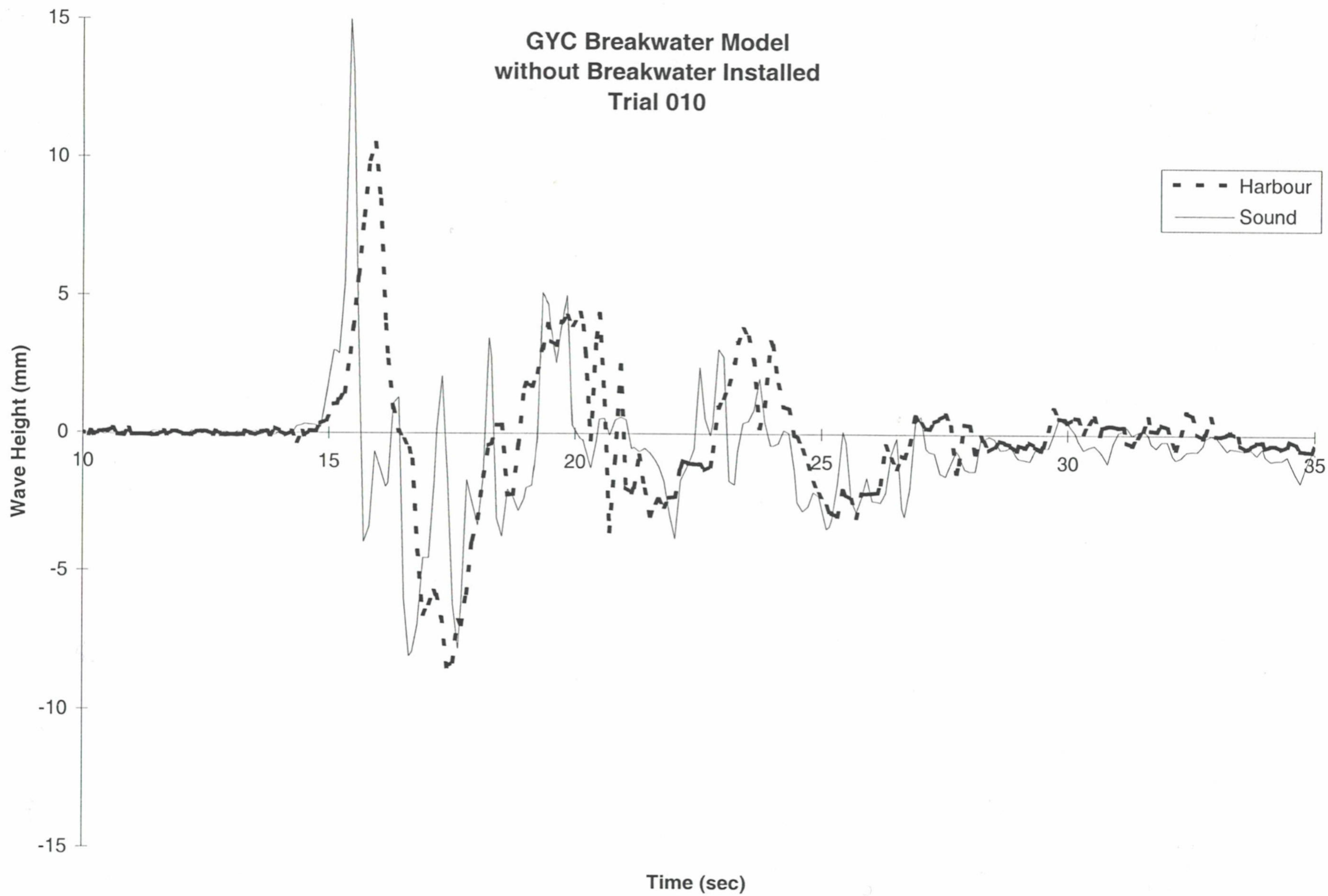
GYC Breakwater Model
without Breakwater Installed
Trial 006
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
10
15
20
25
30
35


GYC Breakwater Model
without Breakwater Installed
Trial 007
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
10
15
20
25
30
35

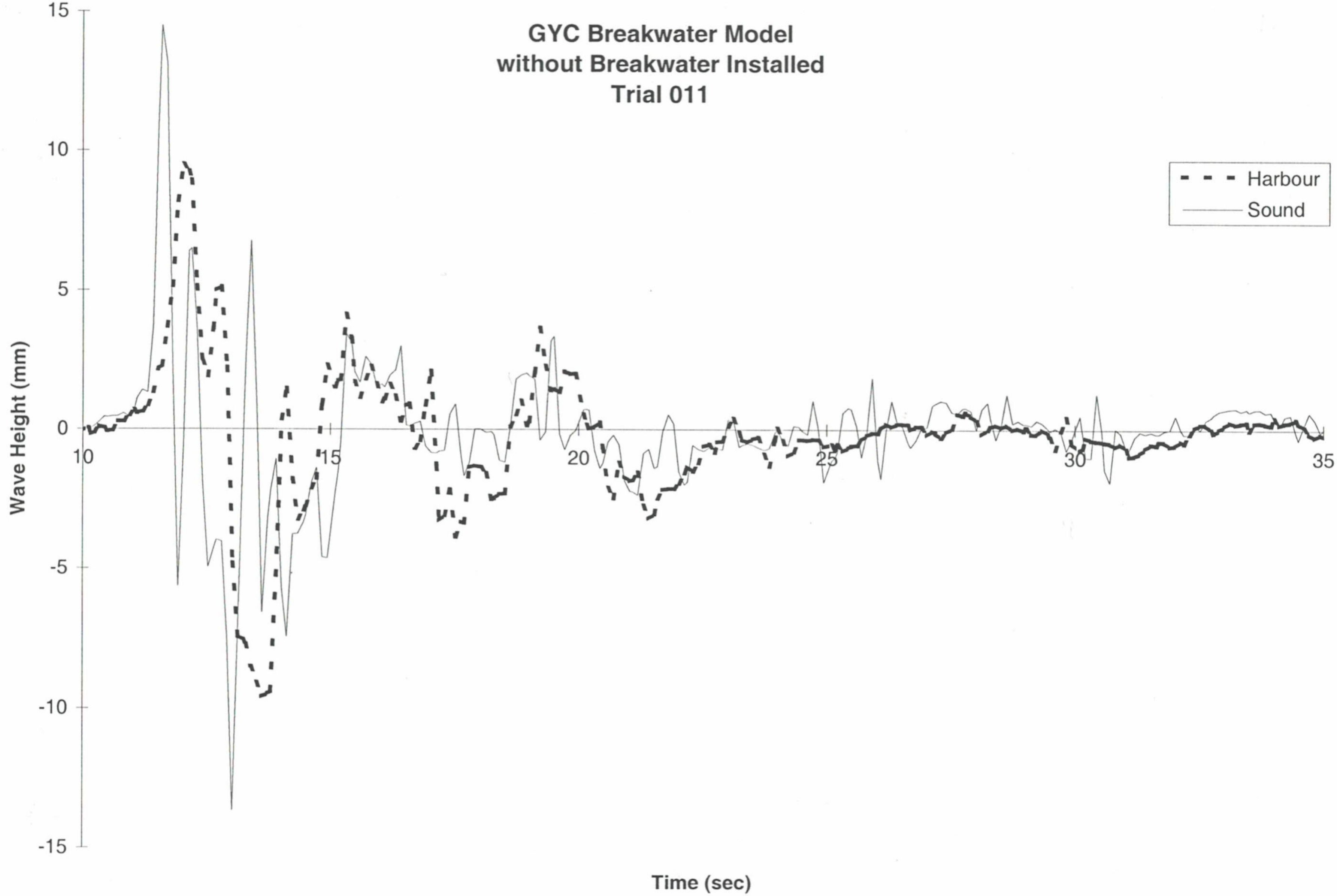

GYC Breakwater Model
without Breakwater Installed
Trial 008
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
10
15
20
25
30
35



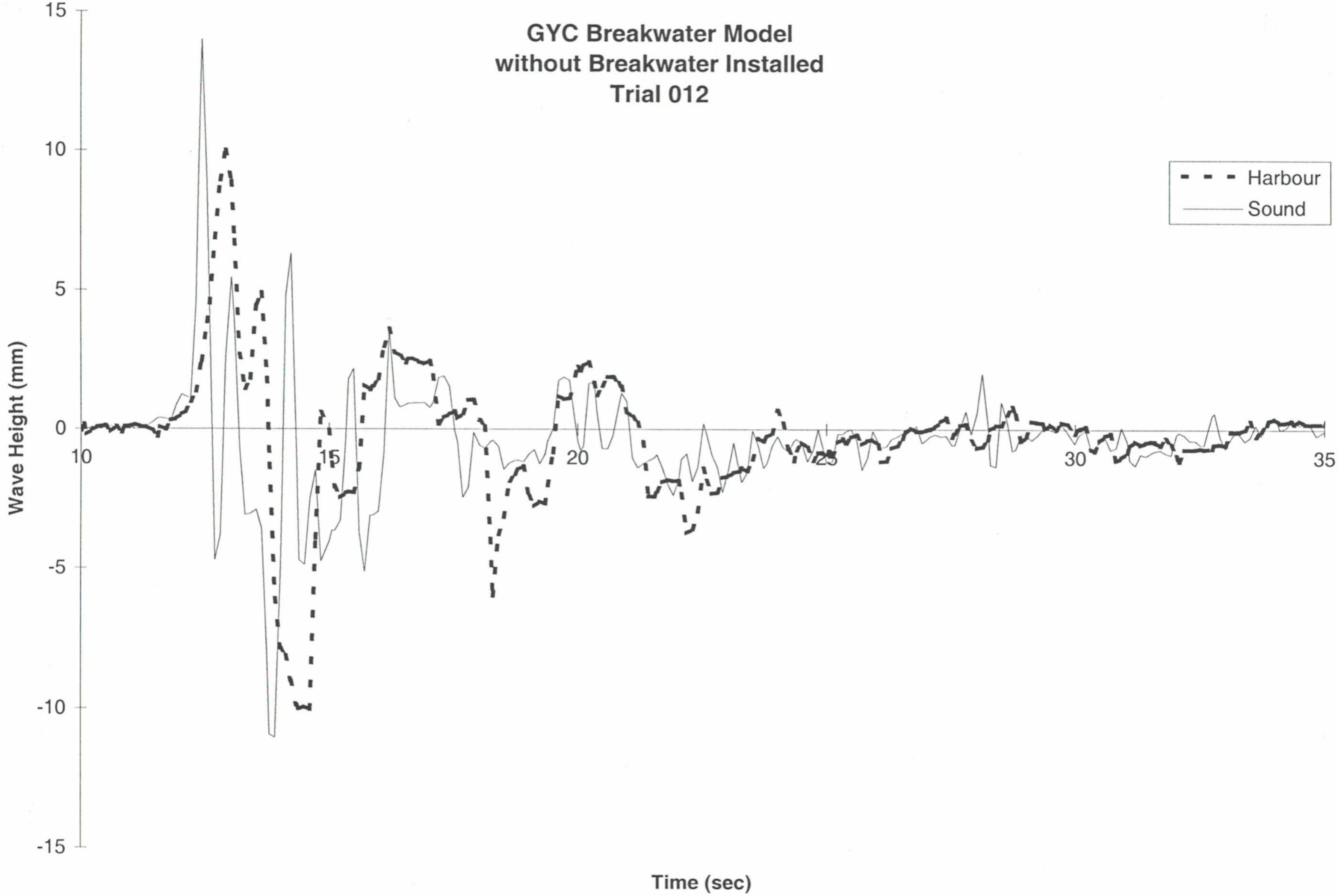
GYC Breakwater Model
without Breakwater Installed
Trial 009
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
10
15
20
25
30
35



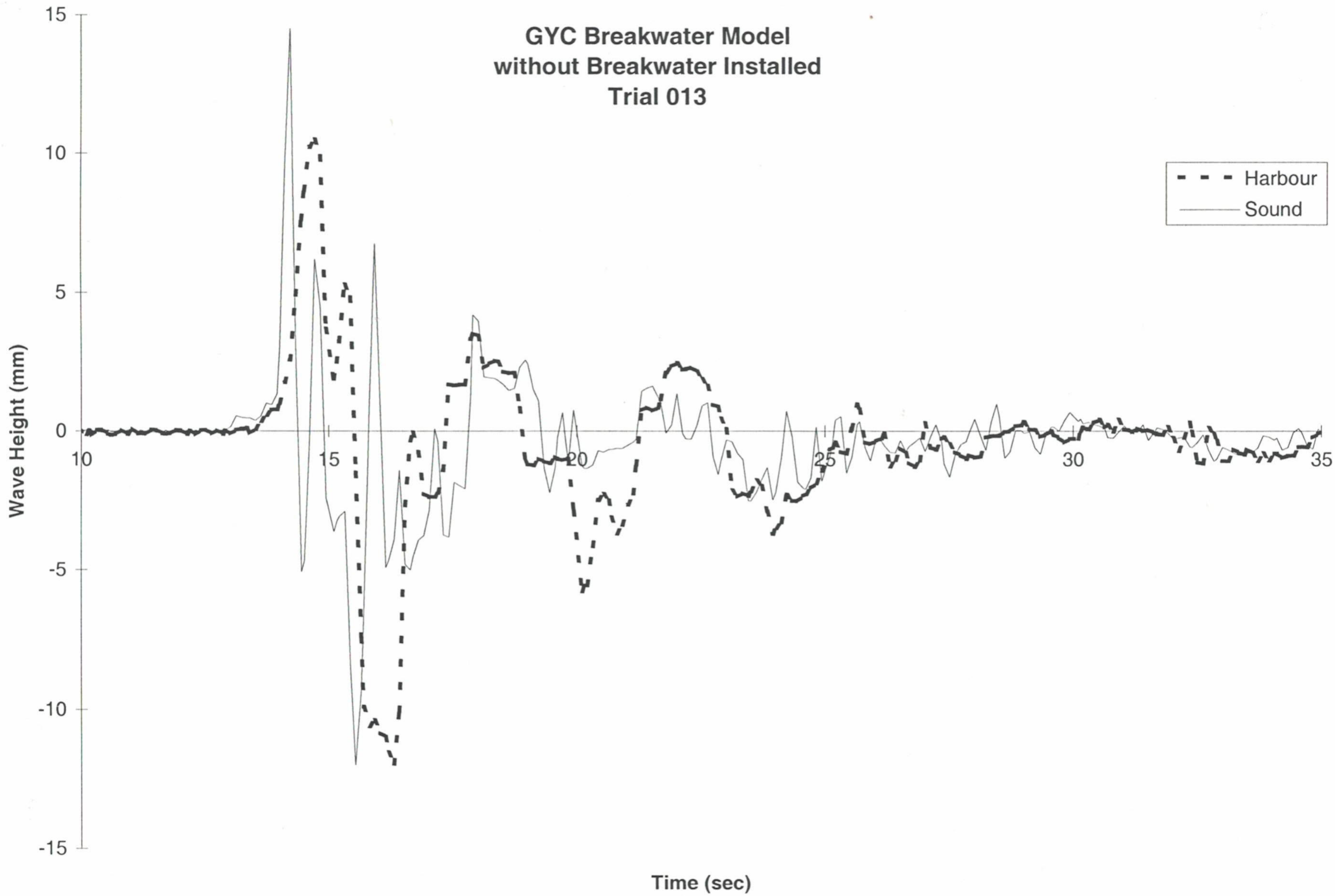
GYC Breakwater Model
without Breakwater Installed
Trial 010
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
10
15
20
25
30
35



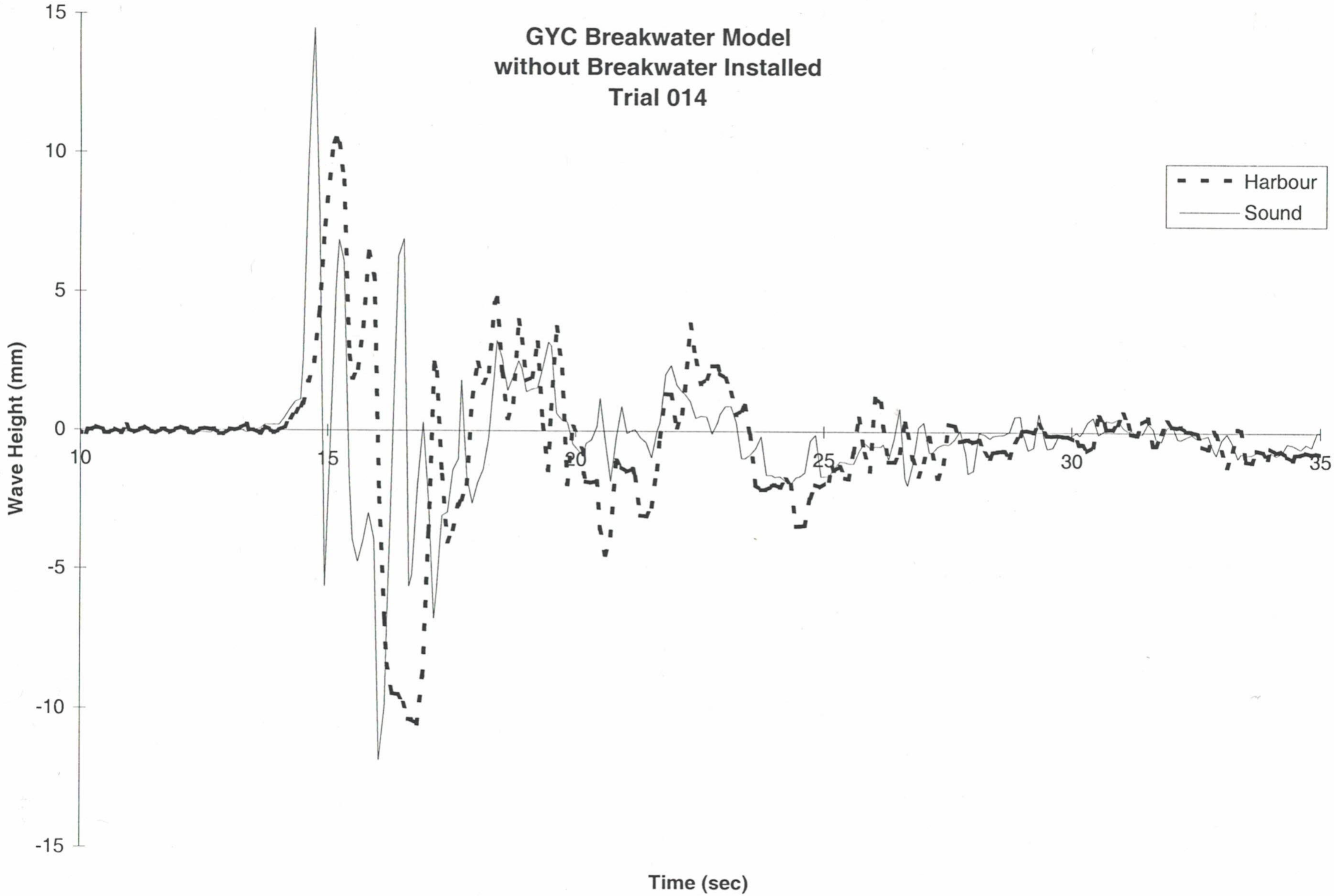
GYC Breakwater Model
without Breakwater Installed
Trial 011
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
10
15
20
25
30
35

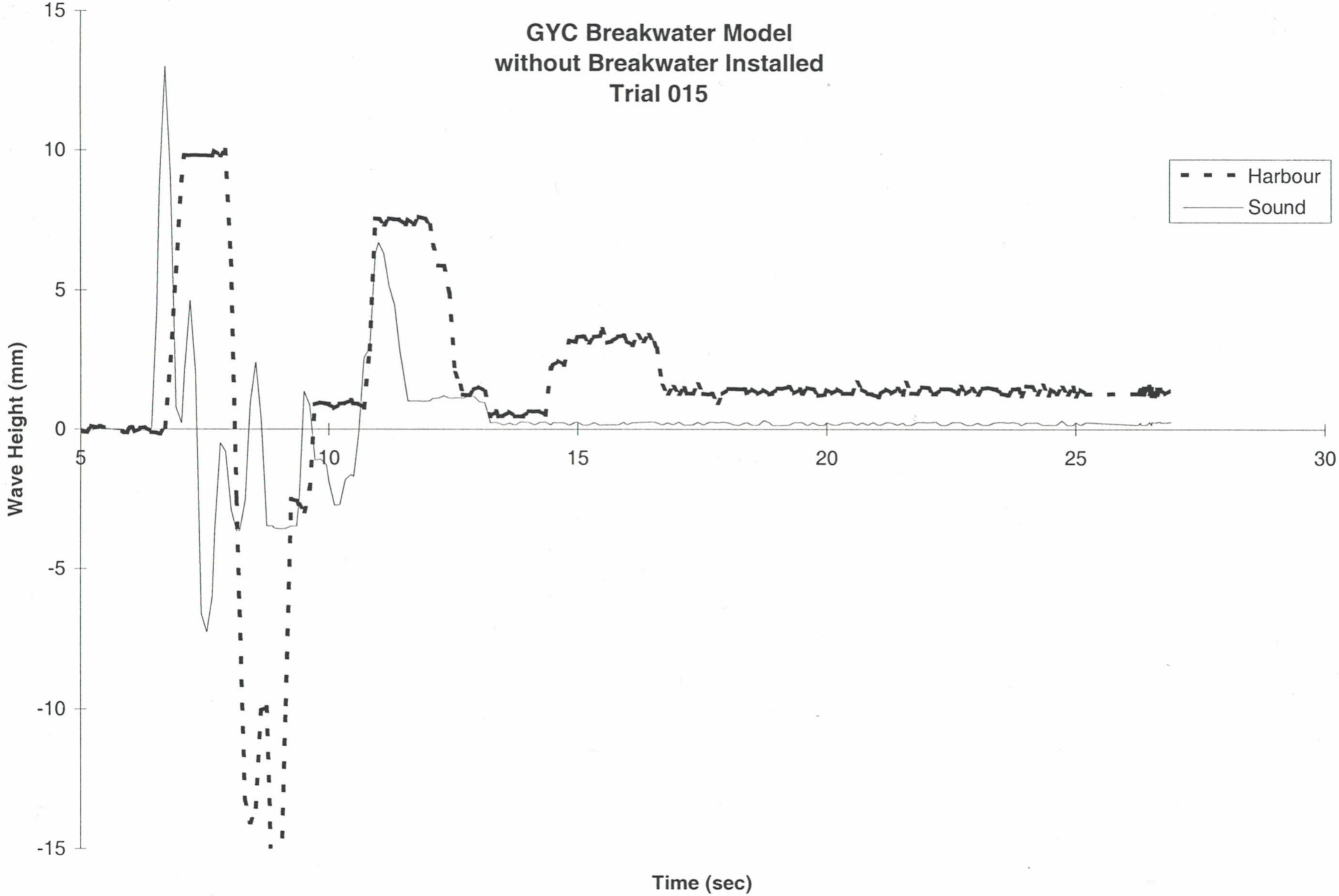


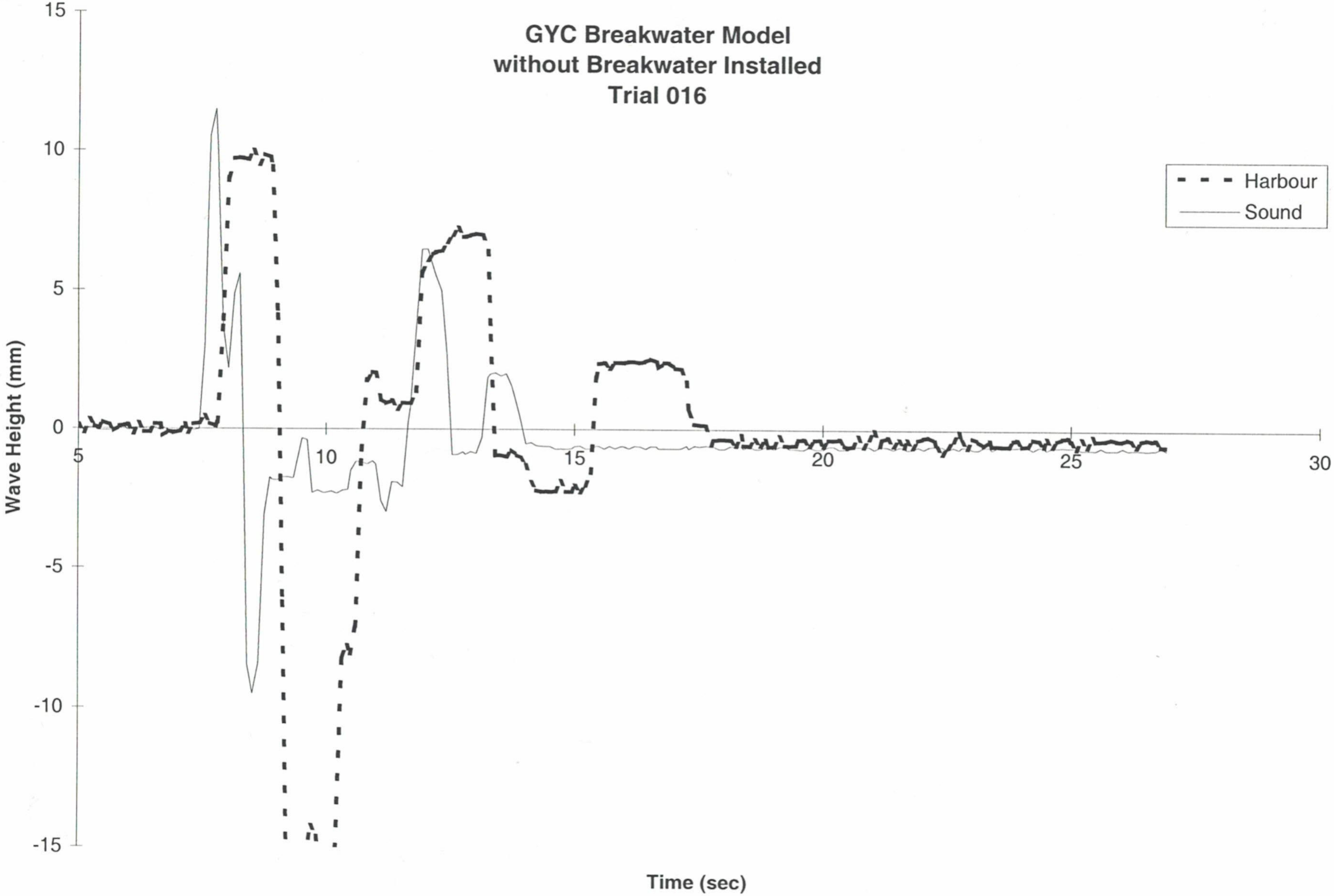
GYC Breakwater Model
without Breakwater Installed
Trial 012
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
10
15
20
25
30
35

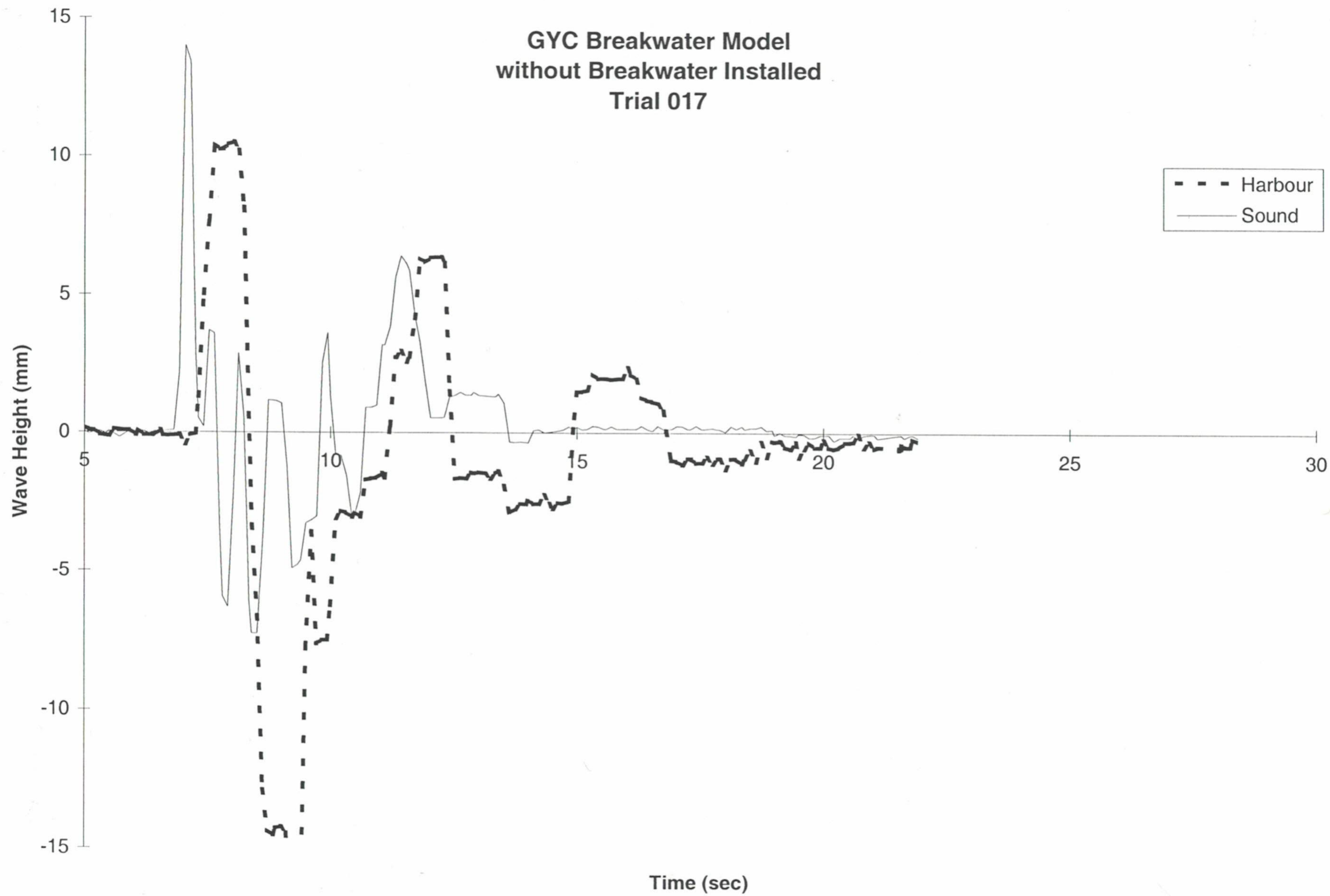


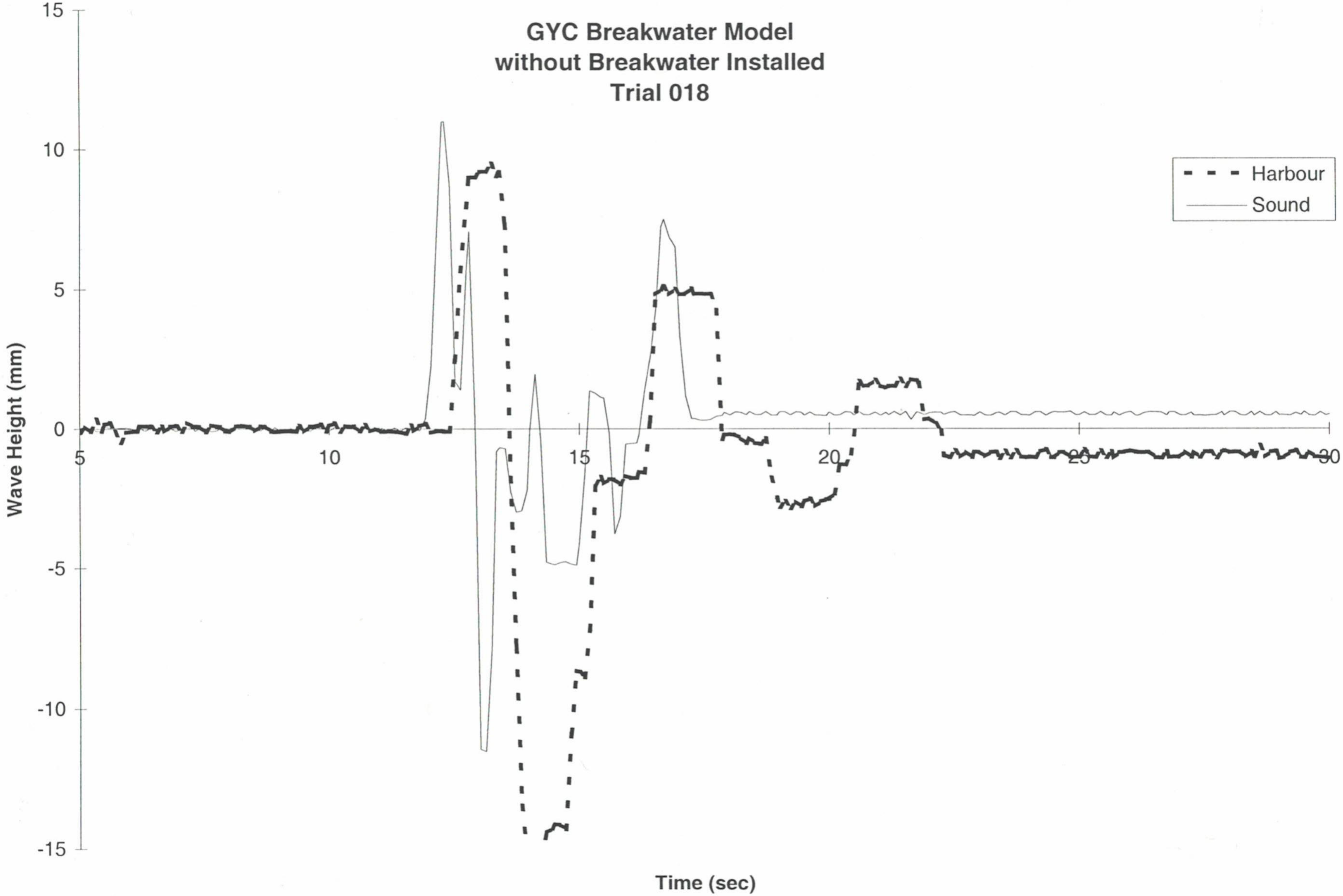
GYC Breakwater Model
without Breakwater Installed
Trial 013
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
10
15
20
25
30
35


GYC Breakwater Model
without Breakwater Installed
Trial 014
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
10
15
20
25
30
35

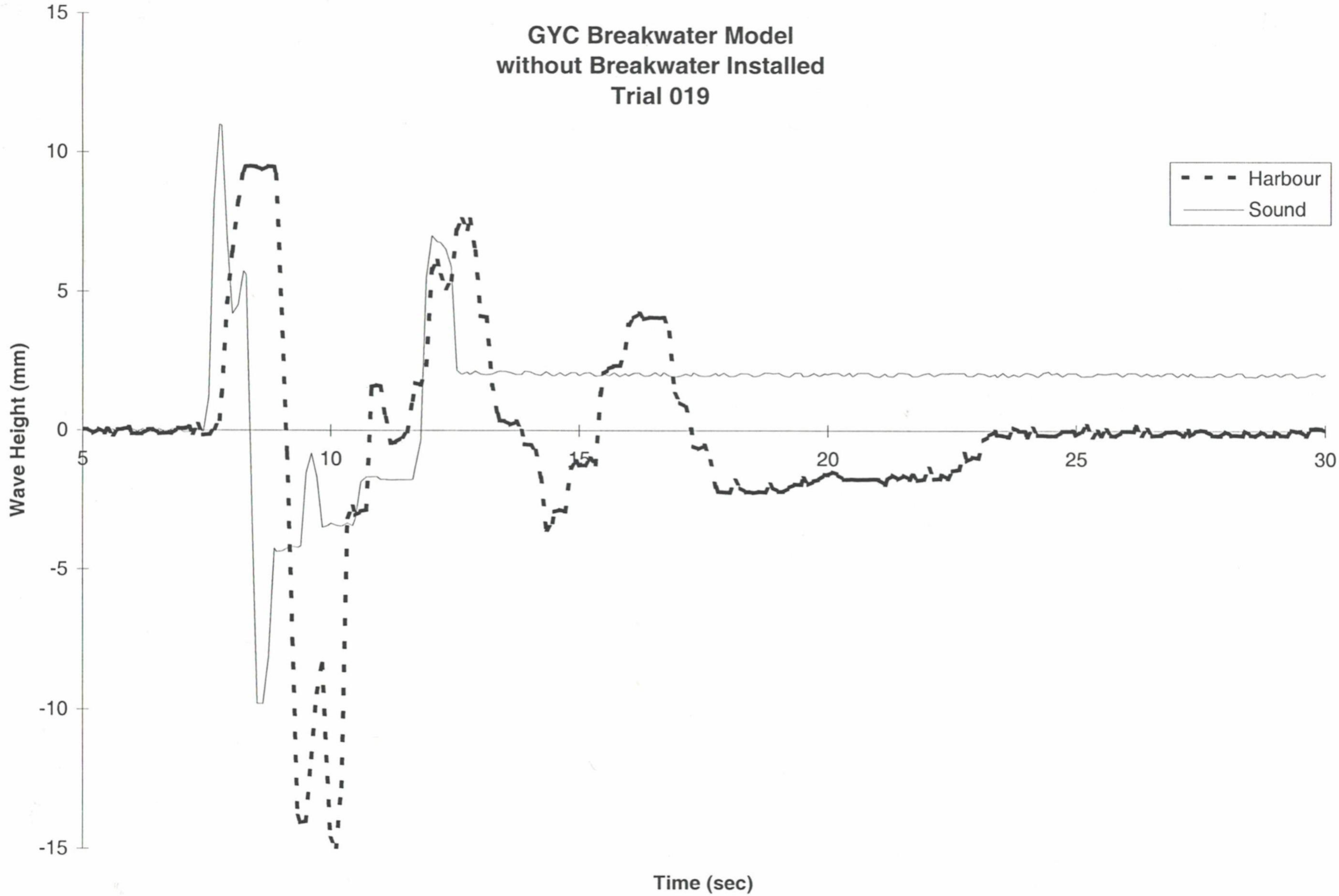

GYC Breakwater Model
without Breakwater Installed
Trial 015
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30


GYC Breakwater Model
without Breakwater Installed
Trial 016
Wave Height (mm)
Time (sec)
Harbour
Sound
15
10
5
0
-5
-10
-15
5
10
15
20
25
30

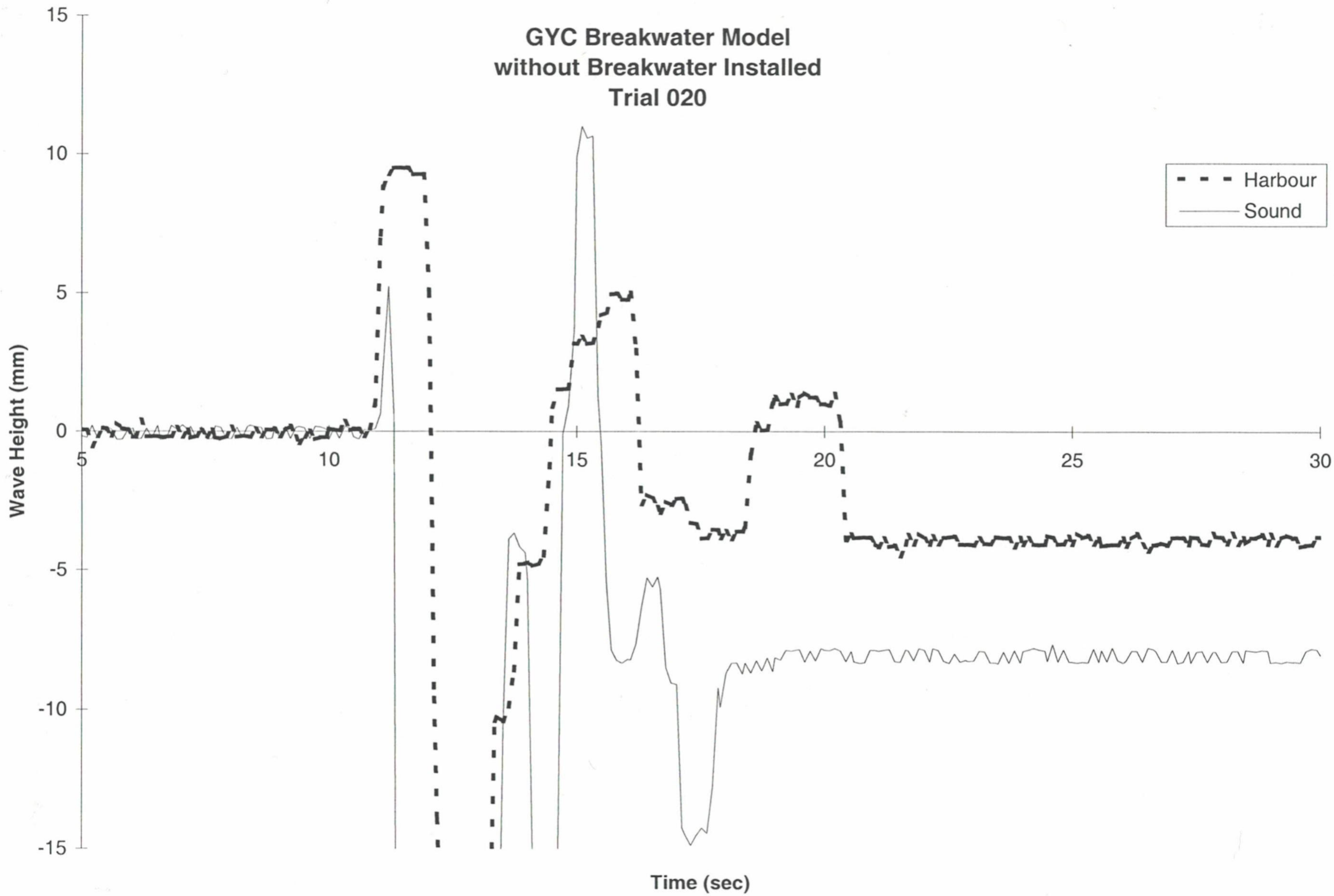

GYC Breakwater Model
without Breakwater Installed
Trial 017
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30

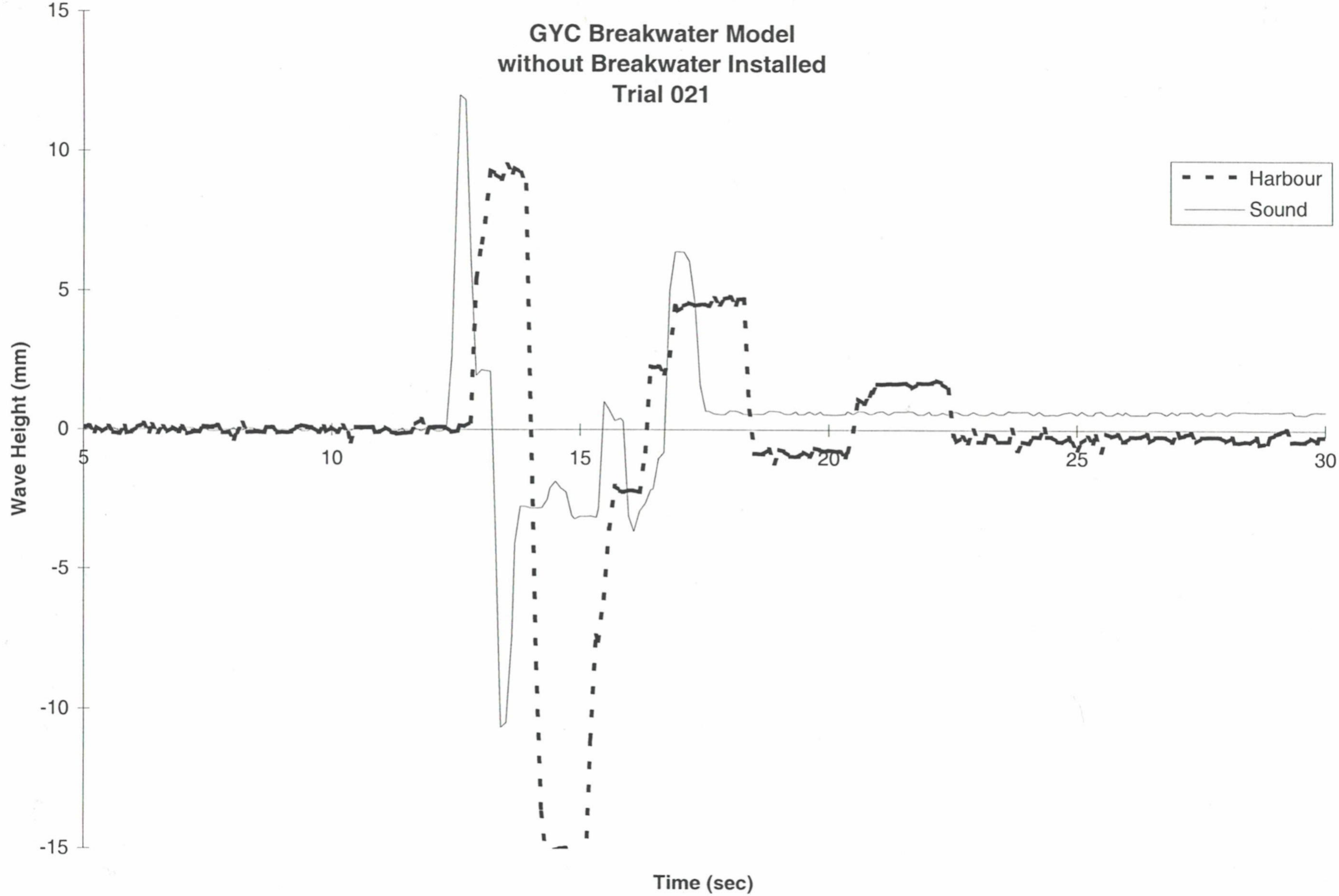


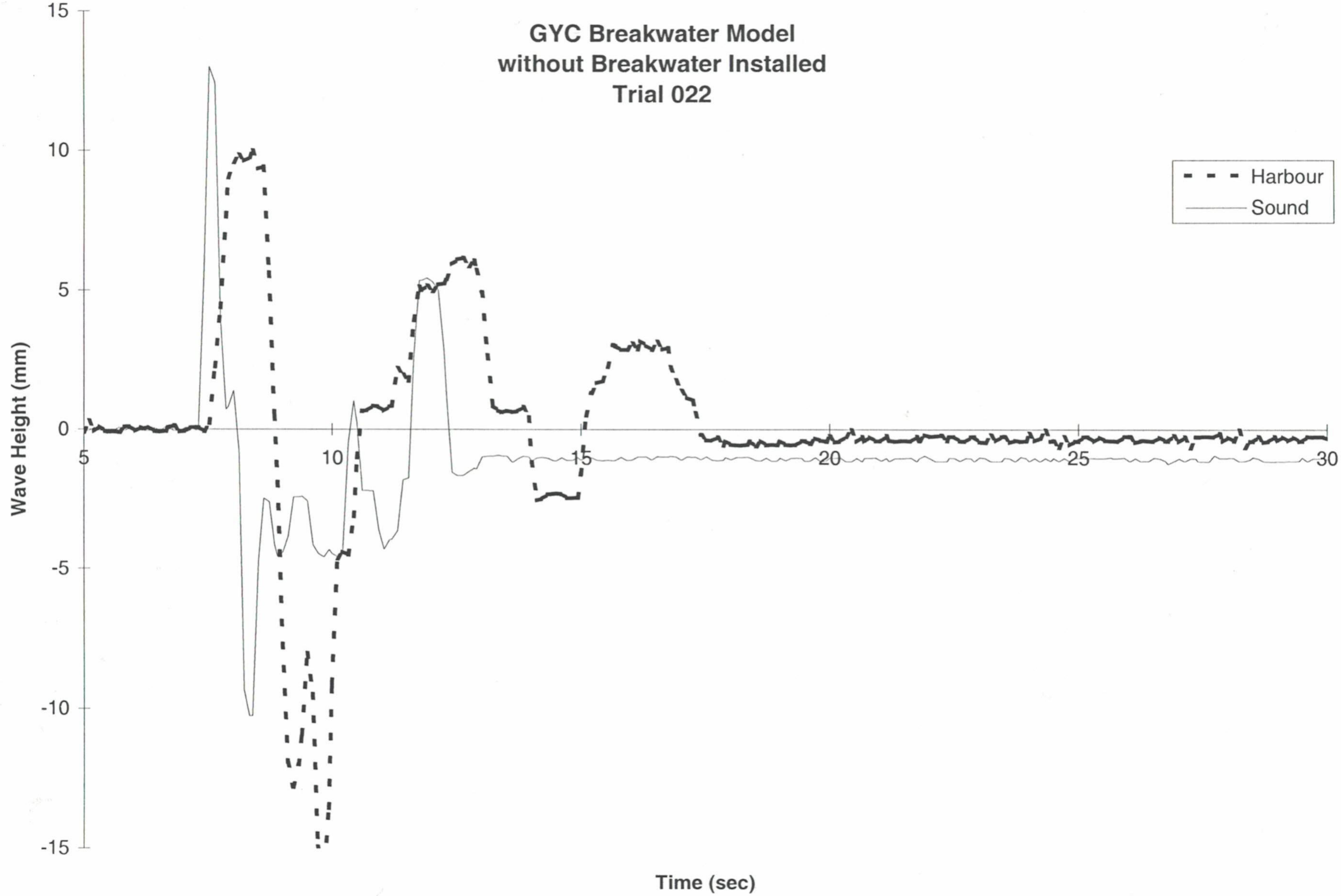
GYC Breakwater Model
without Breakwater Installed
Trial 018
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30



GYC Breakwater Model
without Breakwater Installed
Trial 019
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30


GYC Breakwater Model
without Breakwater Installed
Trial 020
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30


GYC Breakwater Model
without Breakwater Installed
Trial 021
Harbour
Sound
Wave Height (mm)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30
Time (sec)


GYC Breakwater Model
without Breakwater Installed
Trial 022
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
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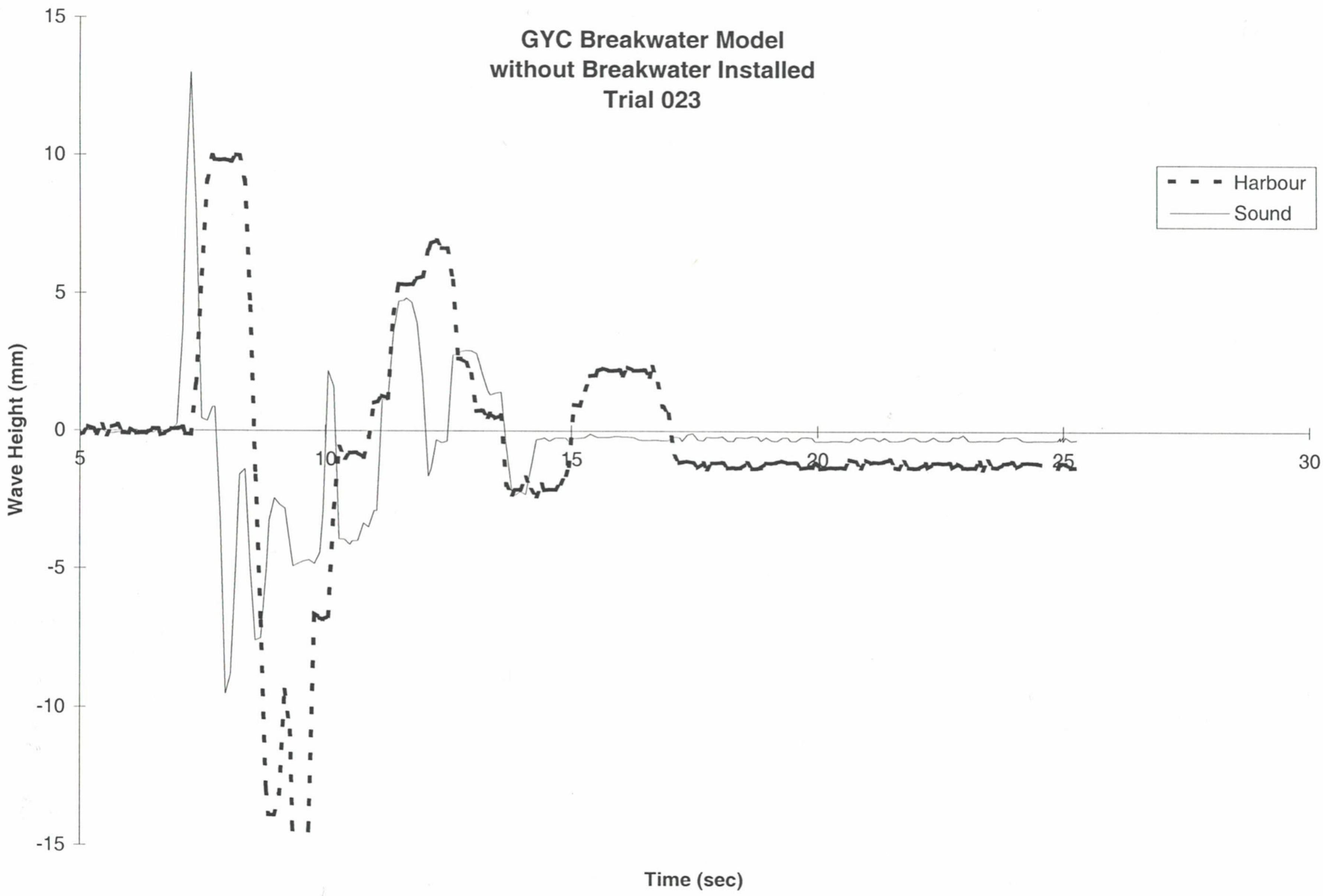
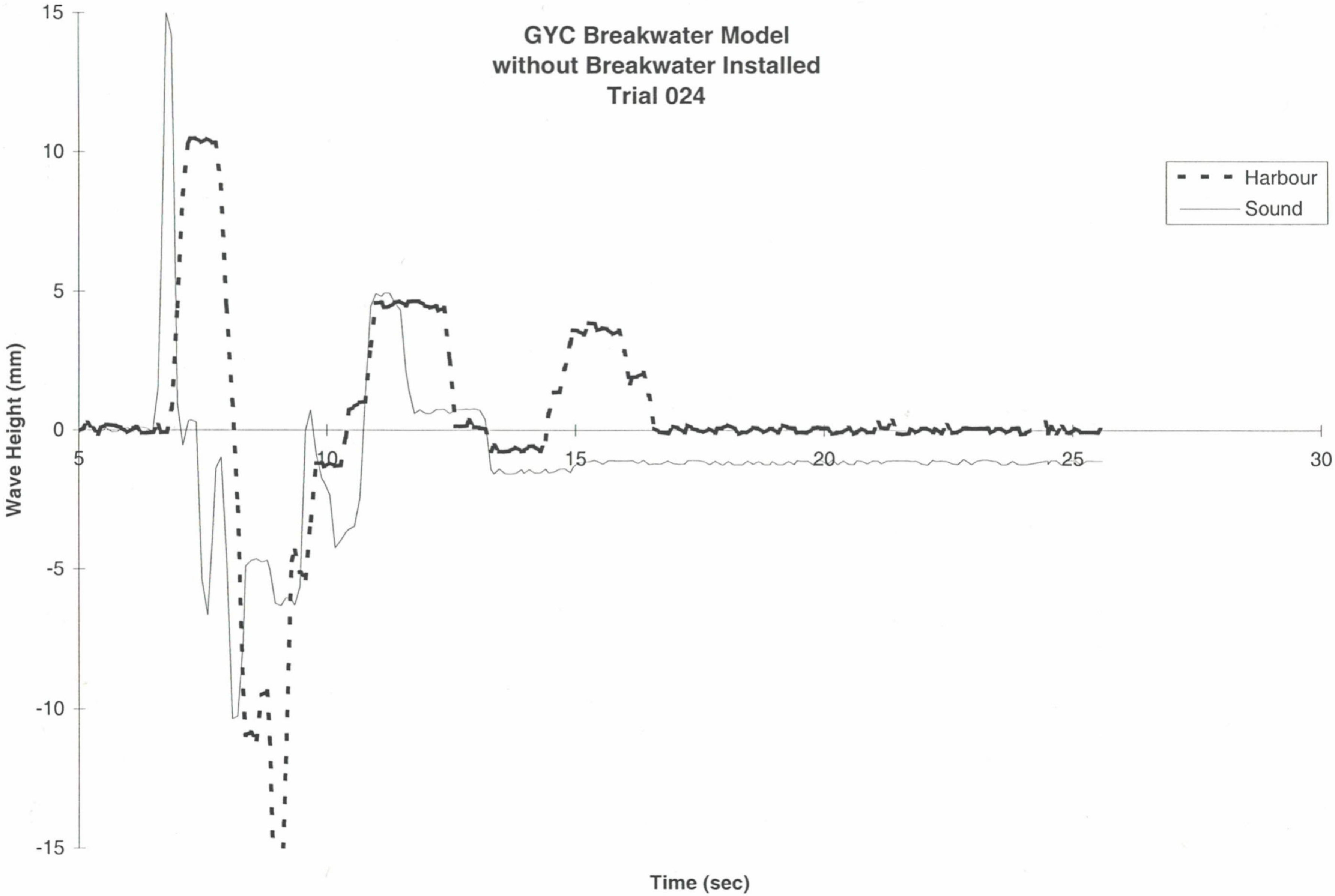
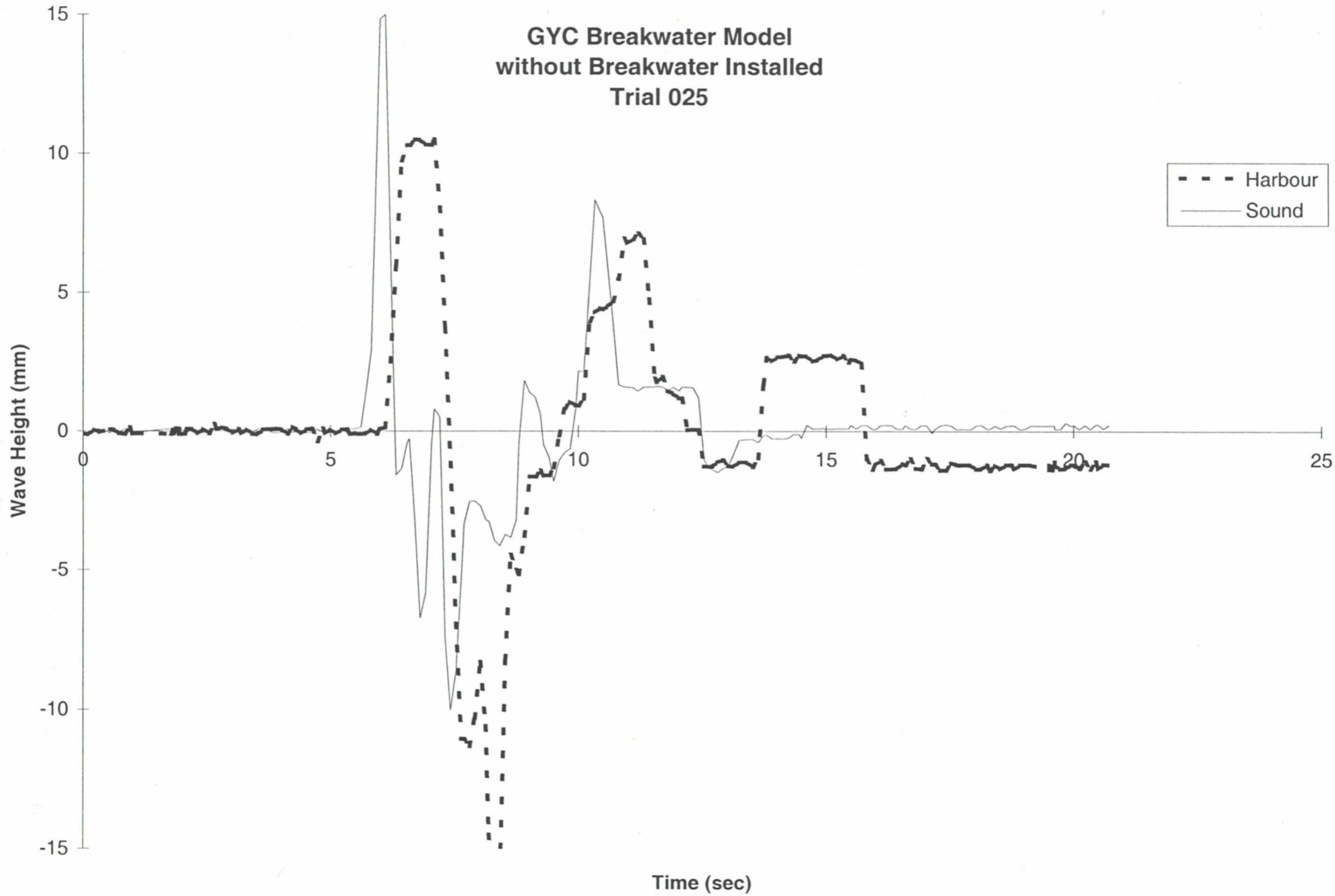
10
15
20
25
30



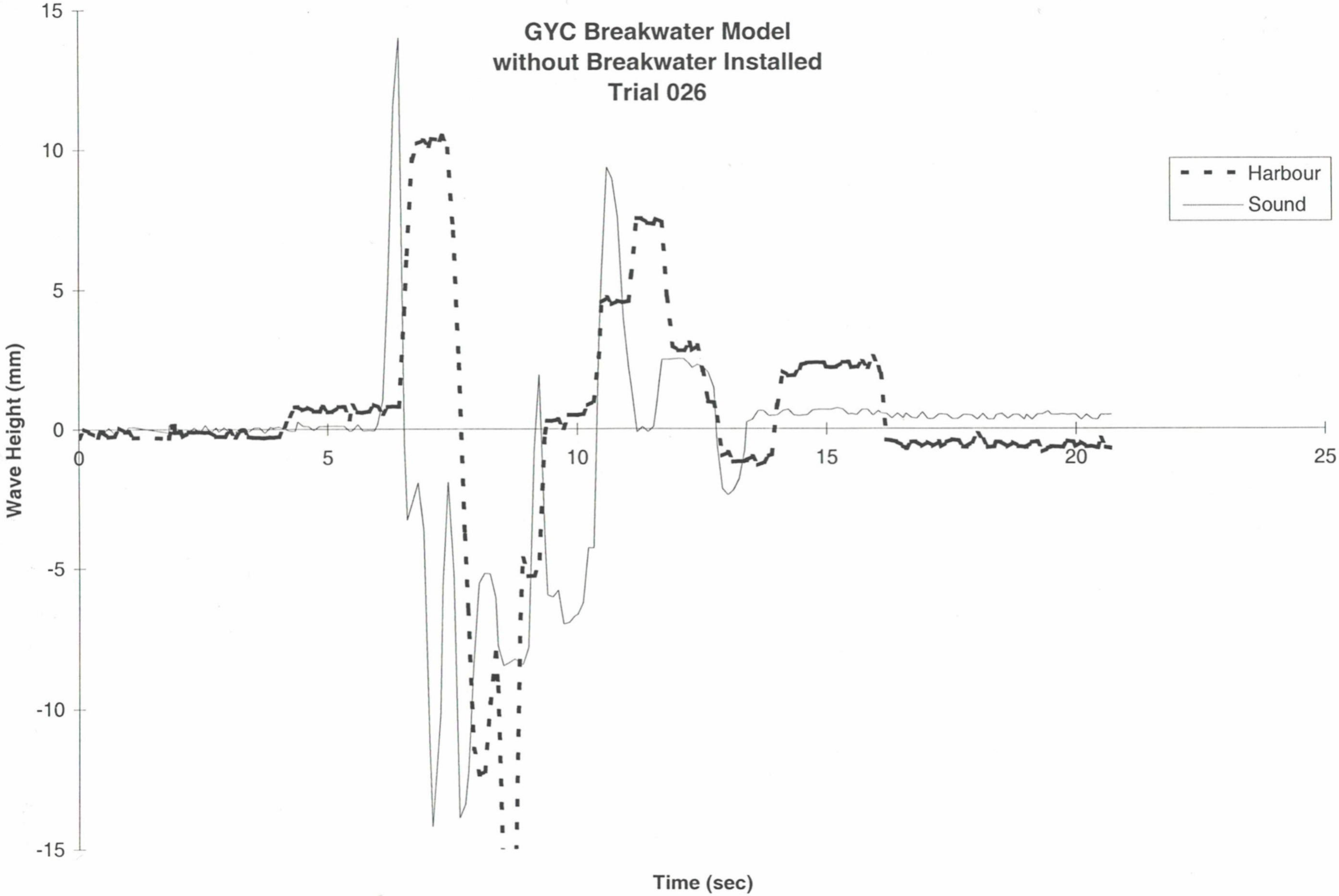
GYC Breakwater Model
without Breakwater Installed
Trial 023
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30

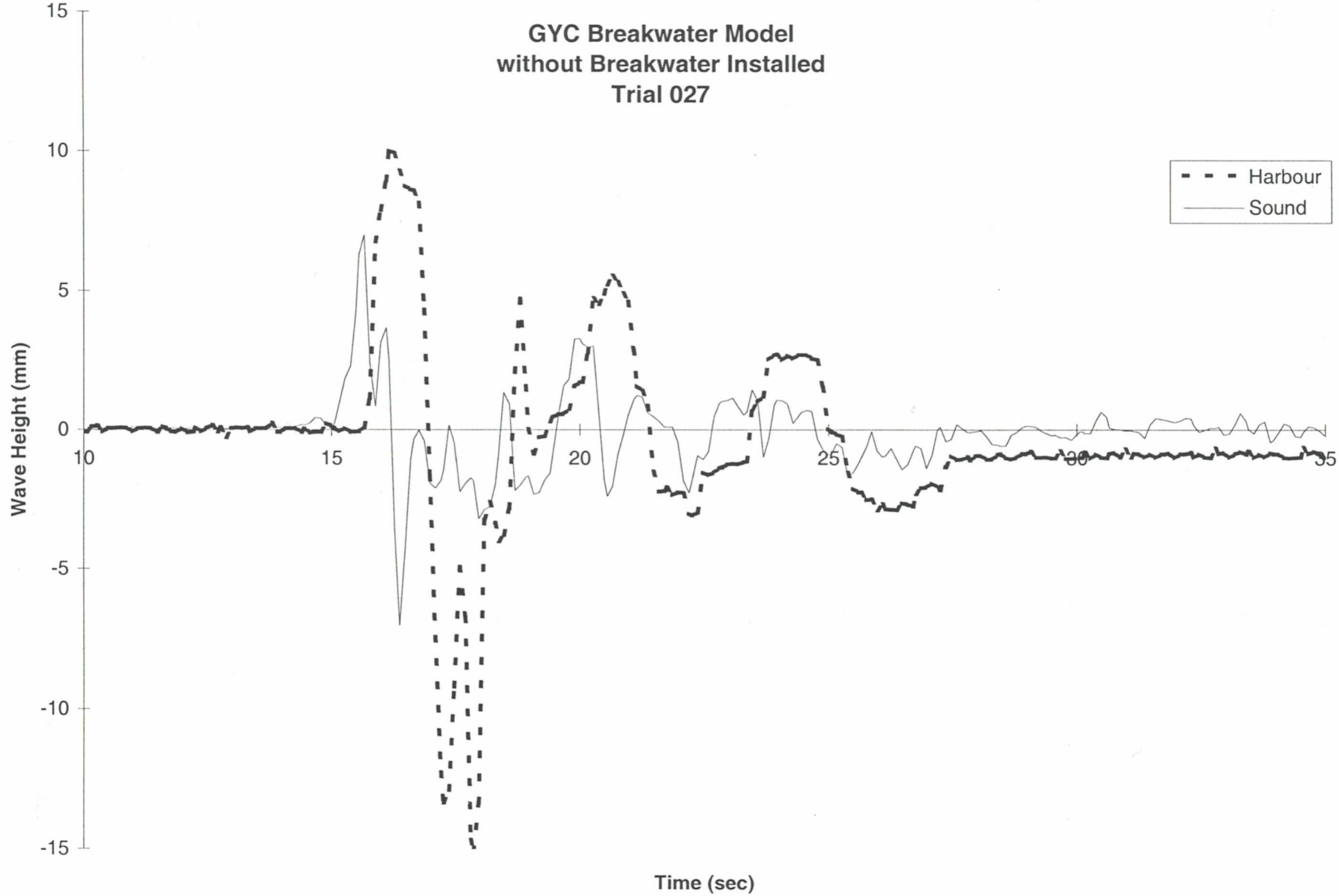


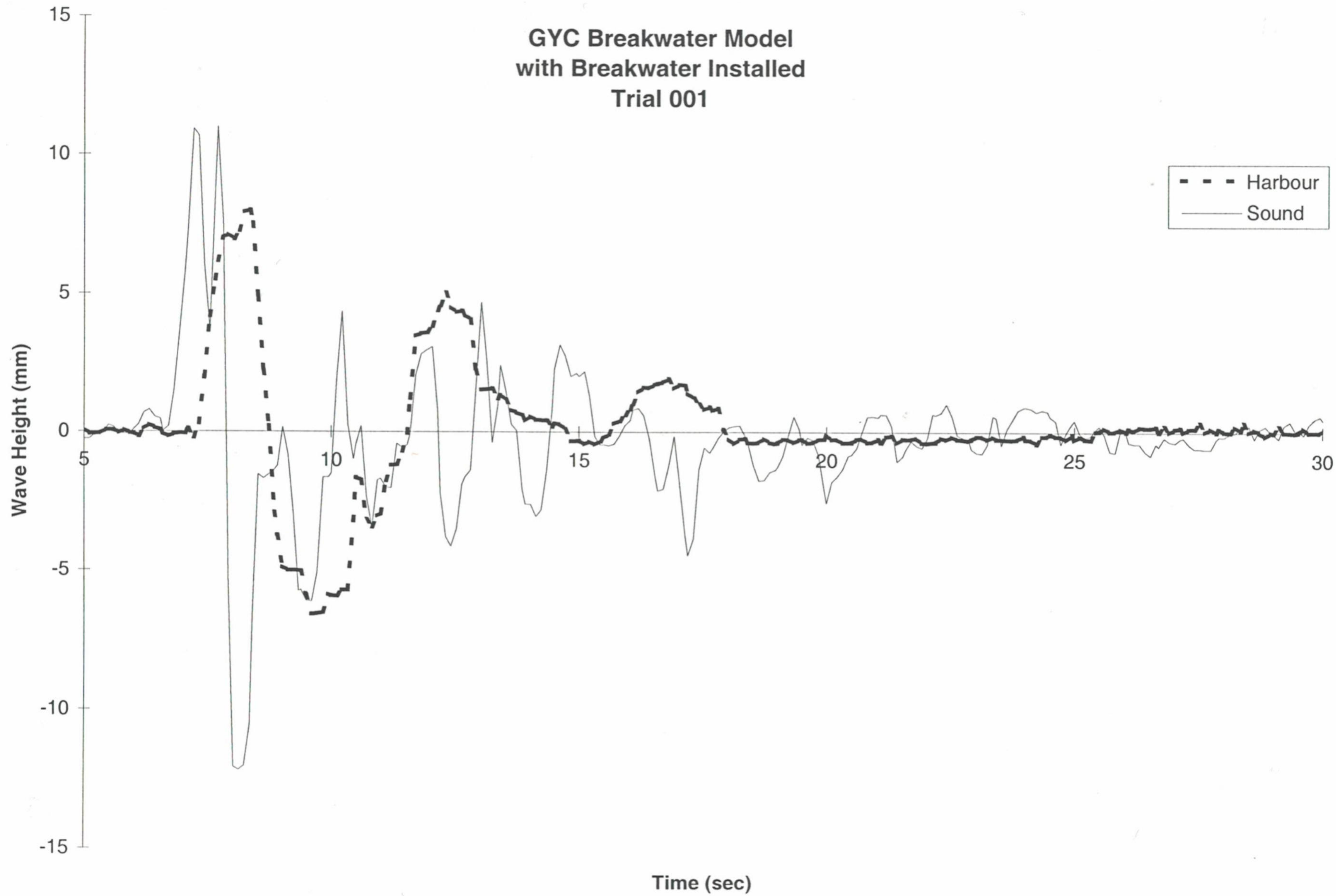
GYC Breakwater Model
without Breakwater Installed
Trial 024
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30

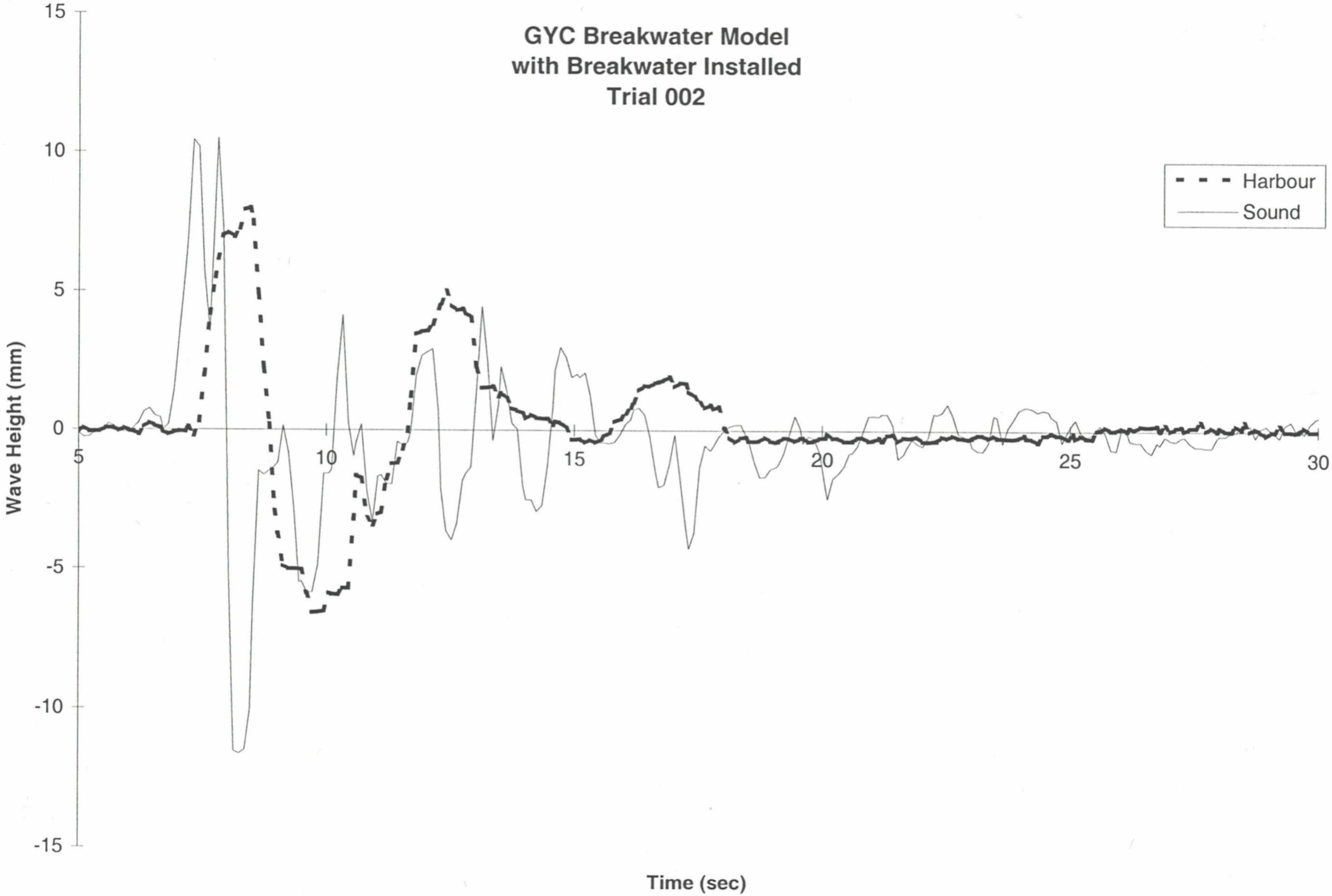


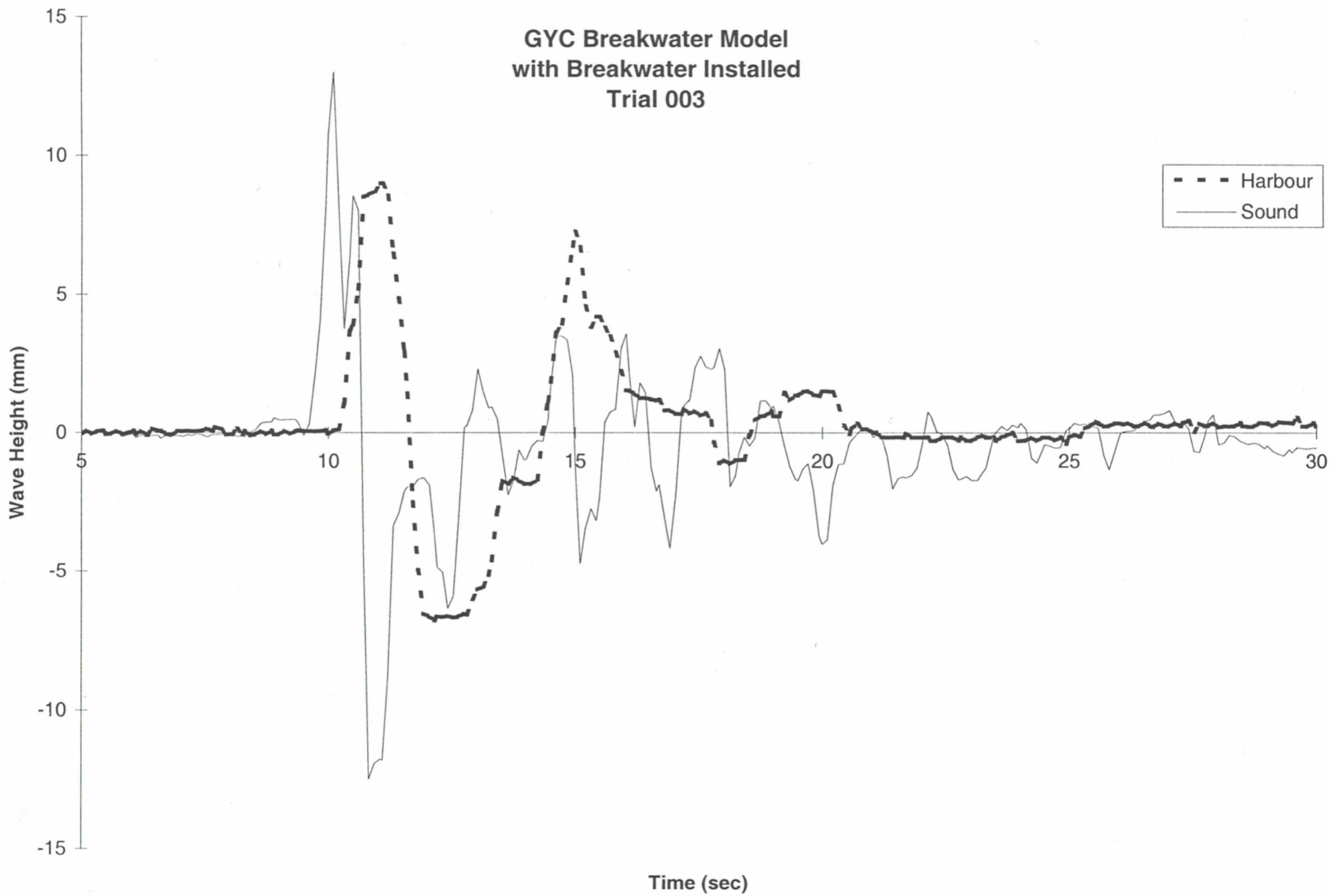
GYC Breakwater Model
without Breakwater Installed
Trial 025
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
0
5
10
15
20
25

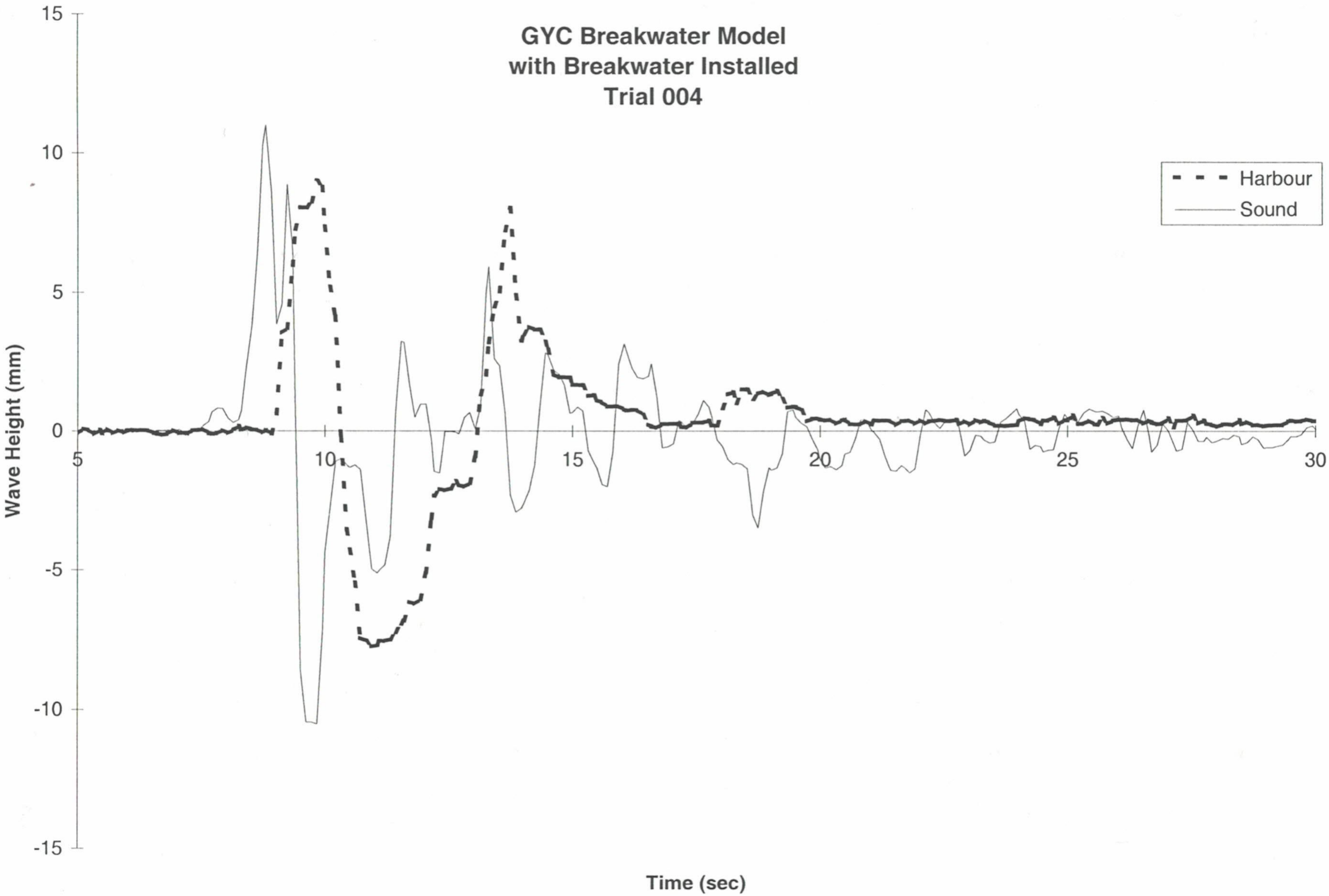

GYC Breakwater Model
without Breakwater Installed
Trial 026
Wave Height (mm)
Time (sec)
Harbour
Sound
15
10
5
0
-5
-10
-15
0
5
10
15
20
25


GYC Breakwater Model
without Breakwater Installed
Trial 027
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
10
15
20
25
30
35


GYC Breakwater Model
with Breakwater Installed
Trial 001
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30


GYC Breakwater Model
with Breakwater Installed
Trial 002
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30


GYC Breakwater Model
with Breakwater Installed
Trial 003
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30



GYC Breakwater Model
with Breakwater Installed
Trial 004
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
5
10
15
20
25
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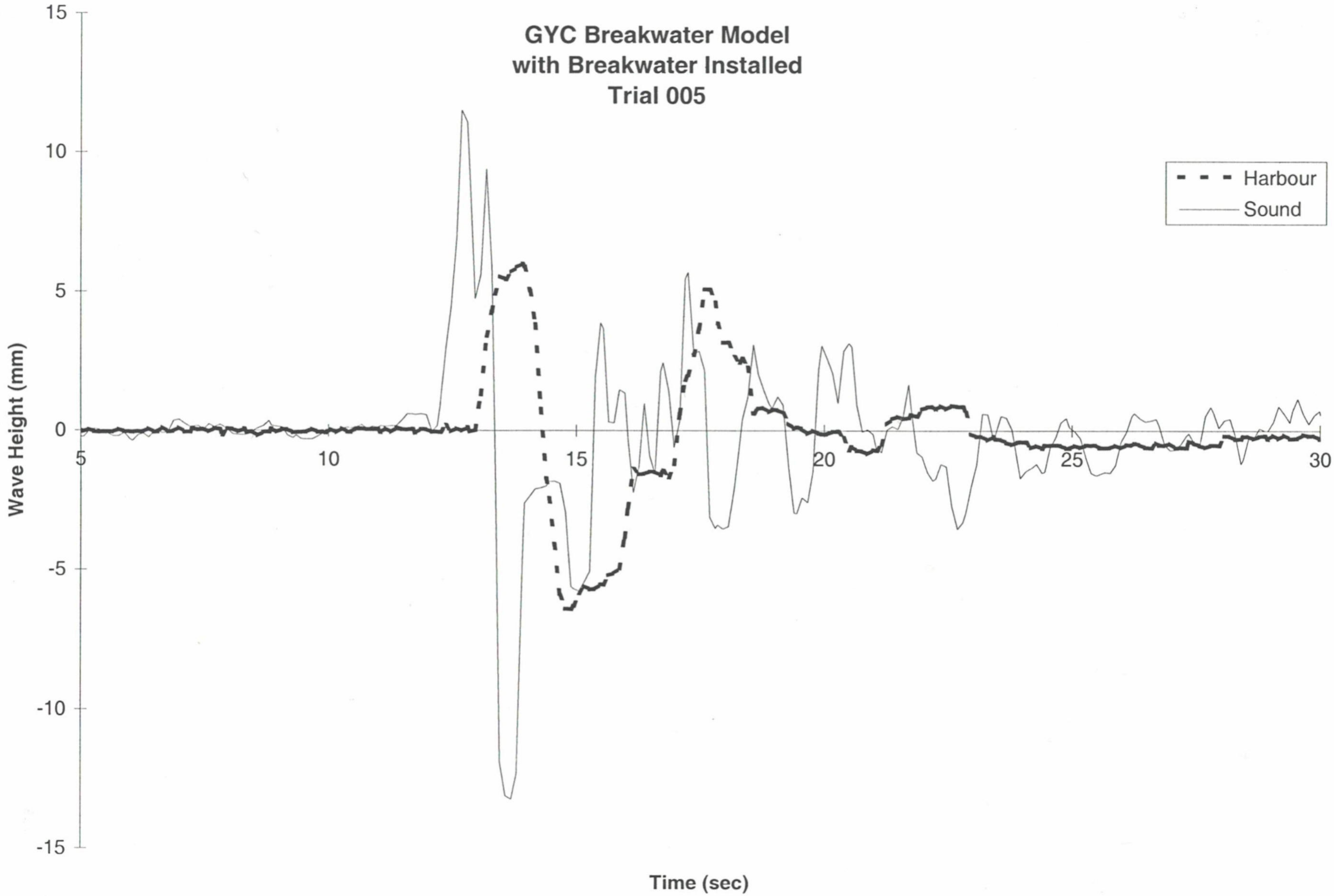
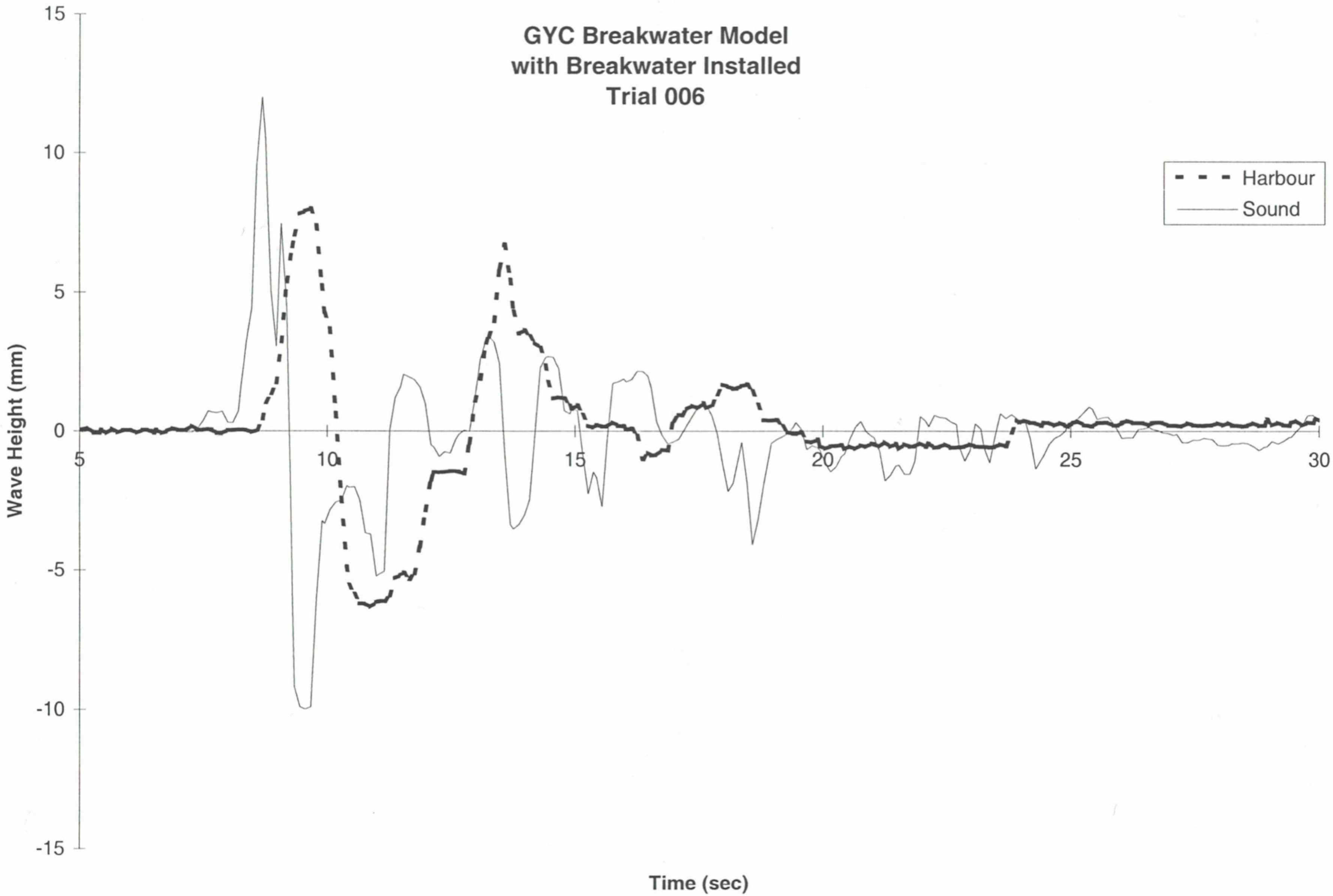


GYC Breakwater Model
with Breakwater Installed
Trial 005
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30


GYC Breakwater Model
with Breakwater Installed
Trial 006
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
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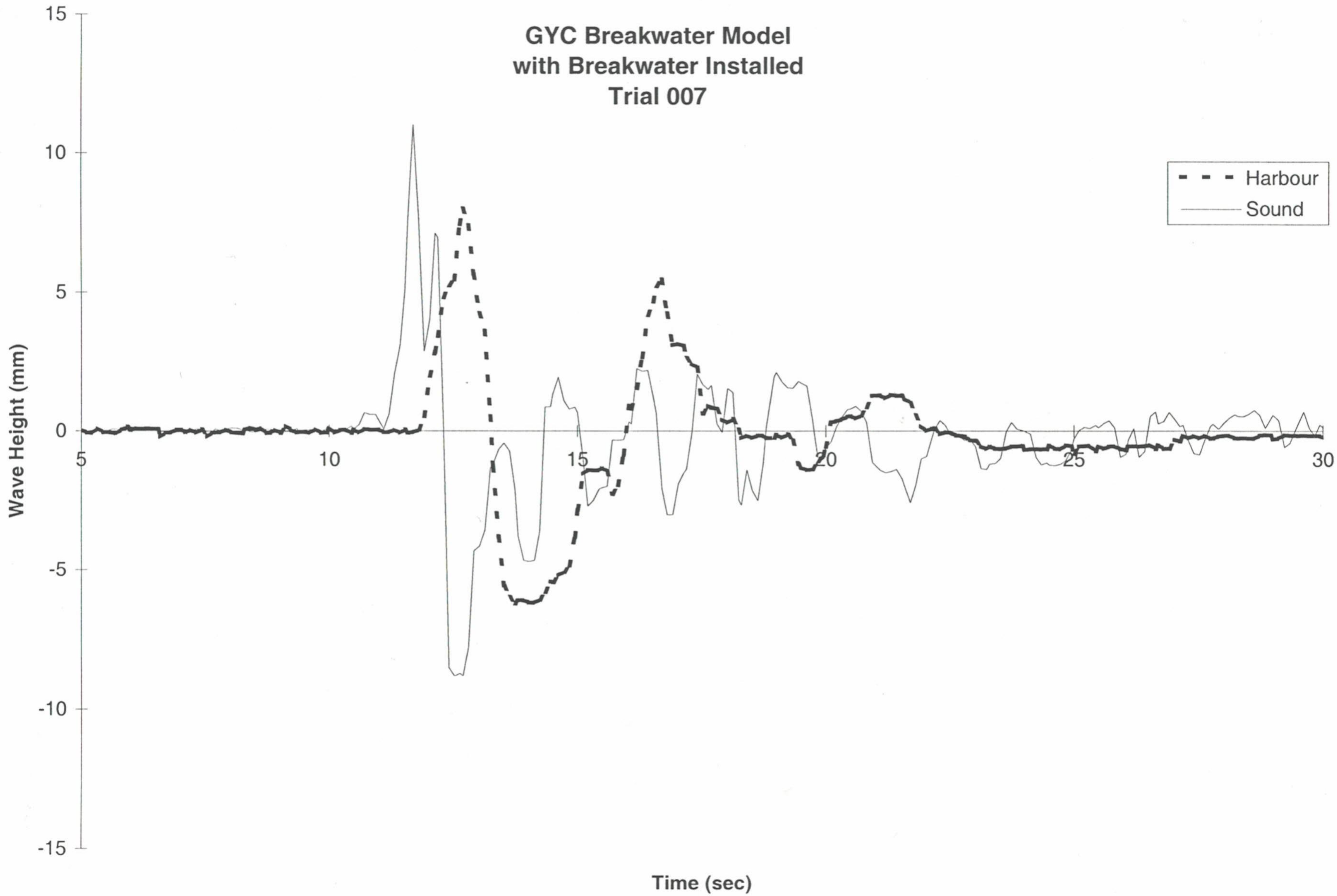
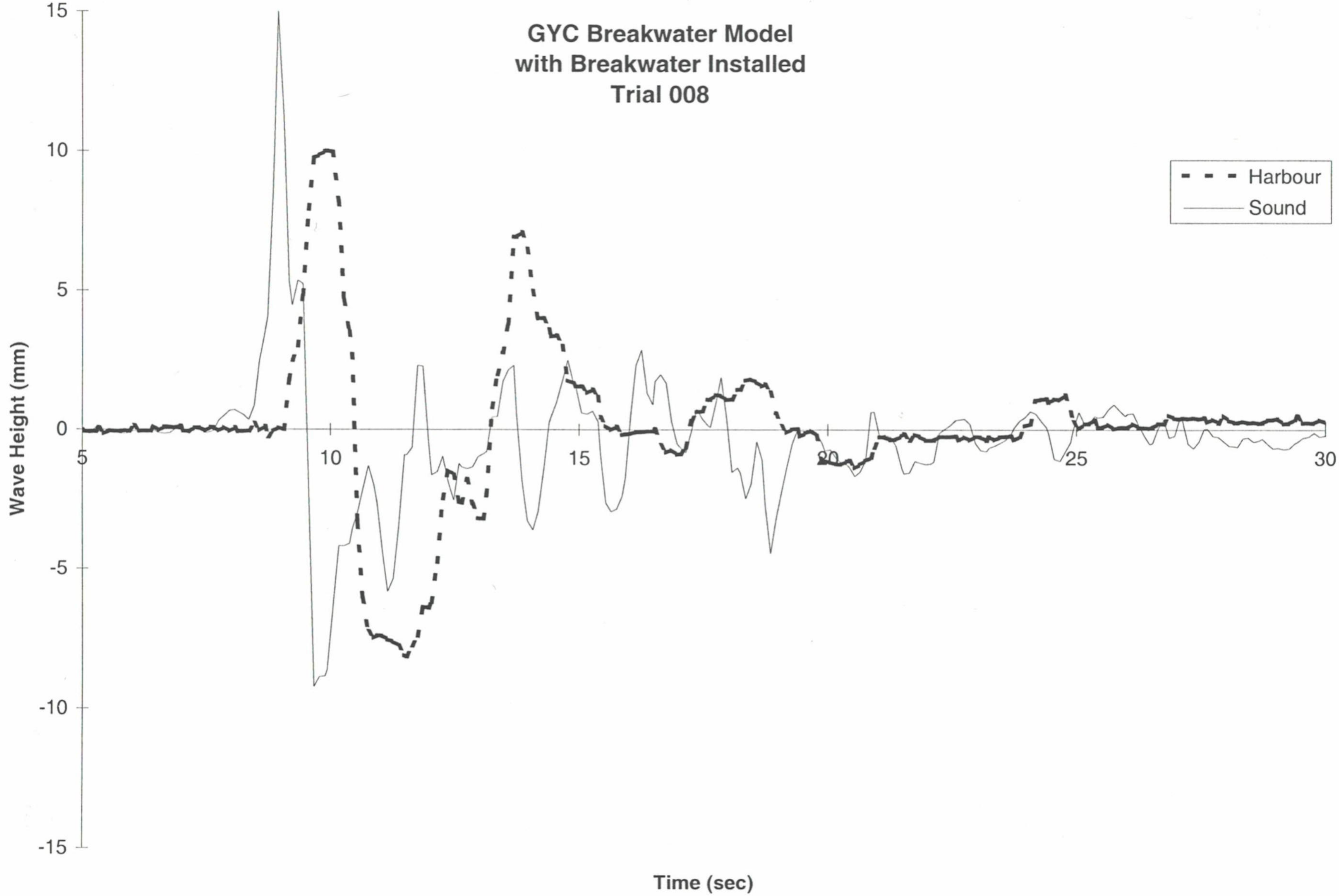
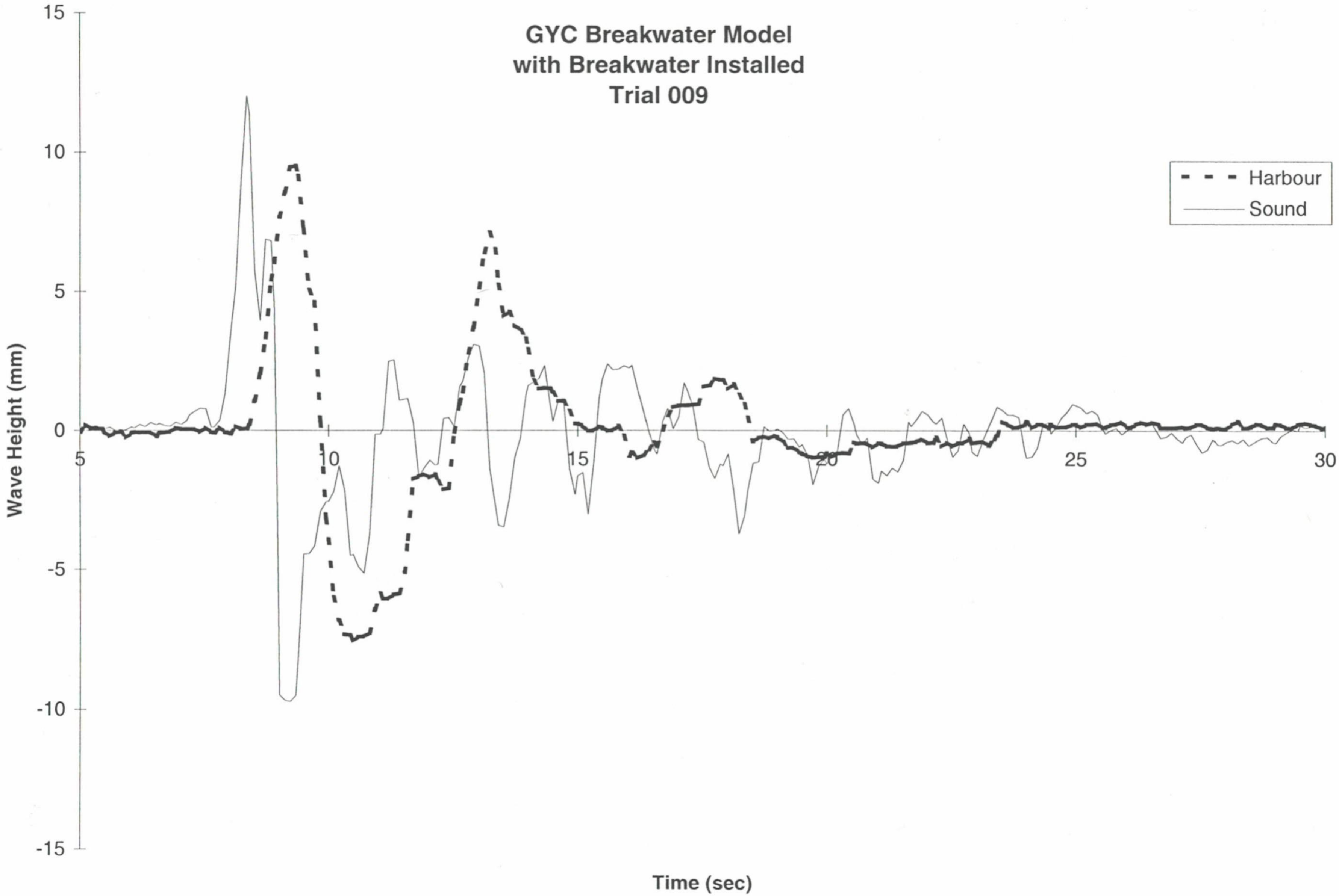
10
15
20
25
30


GYC Breakwater Model
with Breakwater Installed
Trial 007
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30


GYC Breakwater Model
with Breakwater Installed
Trial 008
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30



GYC Breakwater Model
with Breakwater Installed
Trial 009
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
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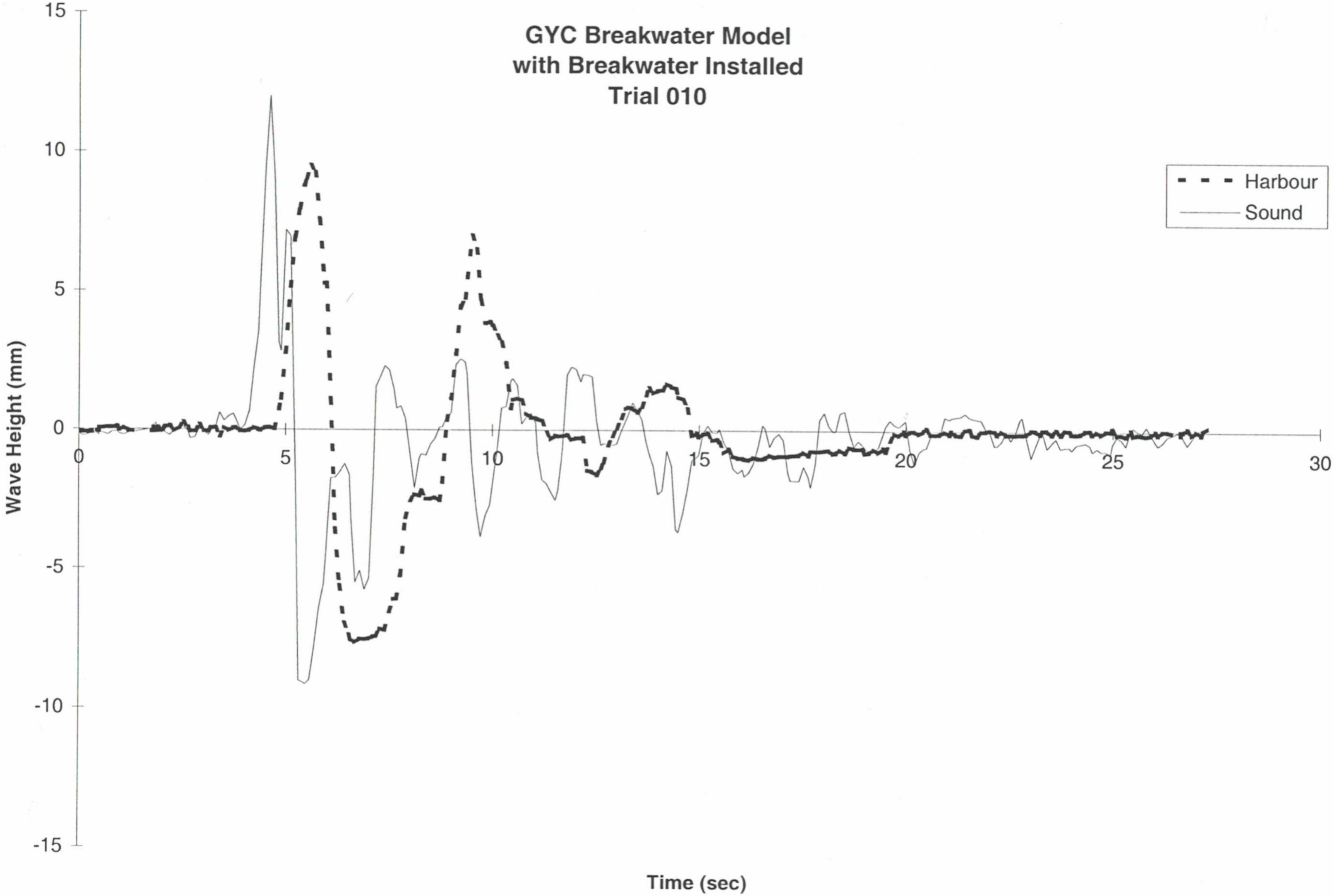
10
15
20
25
30


GYC Breakwater Model
with Breakwater Installed
Trial 010
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
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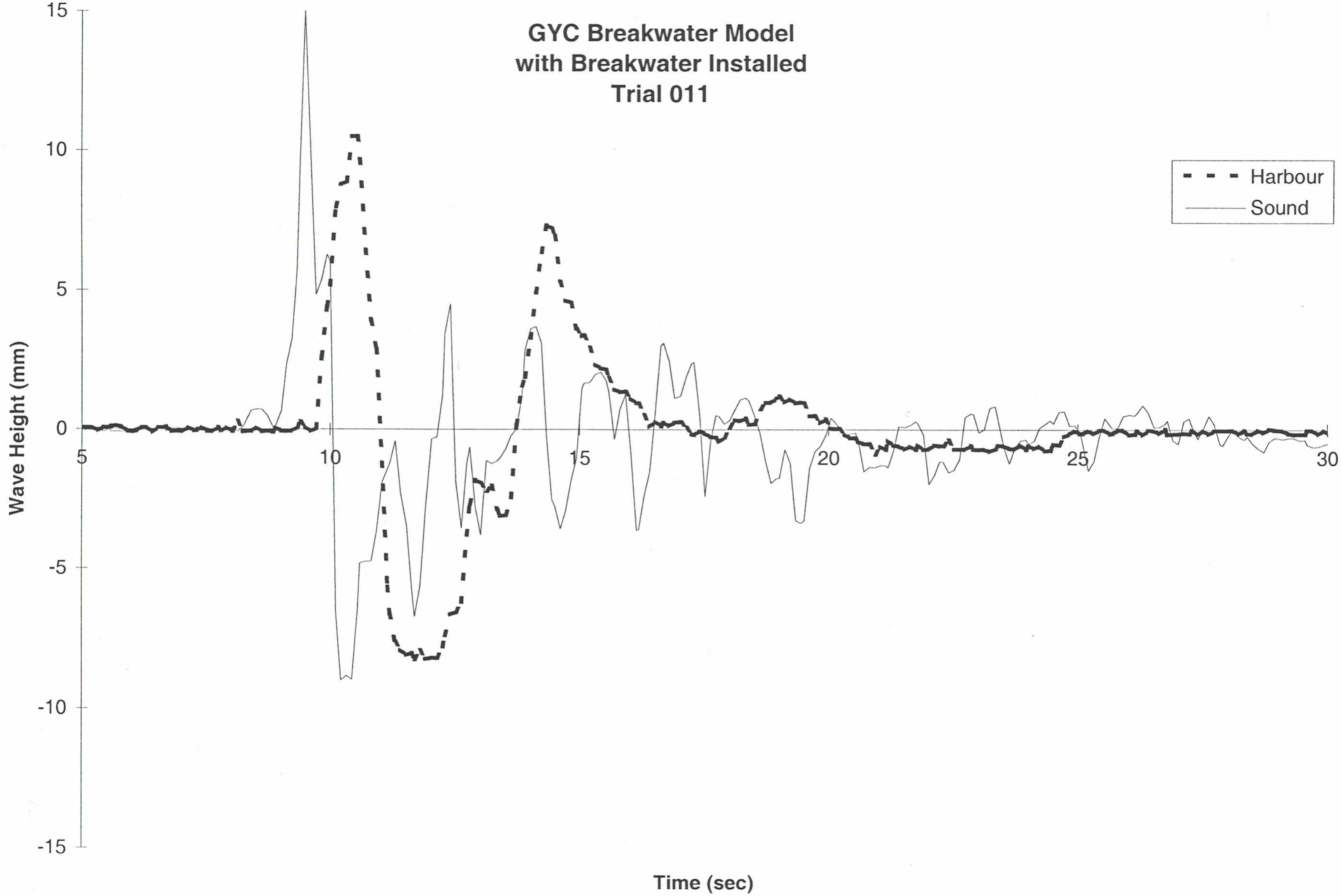
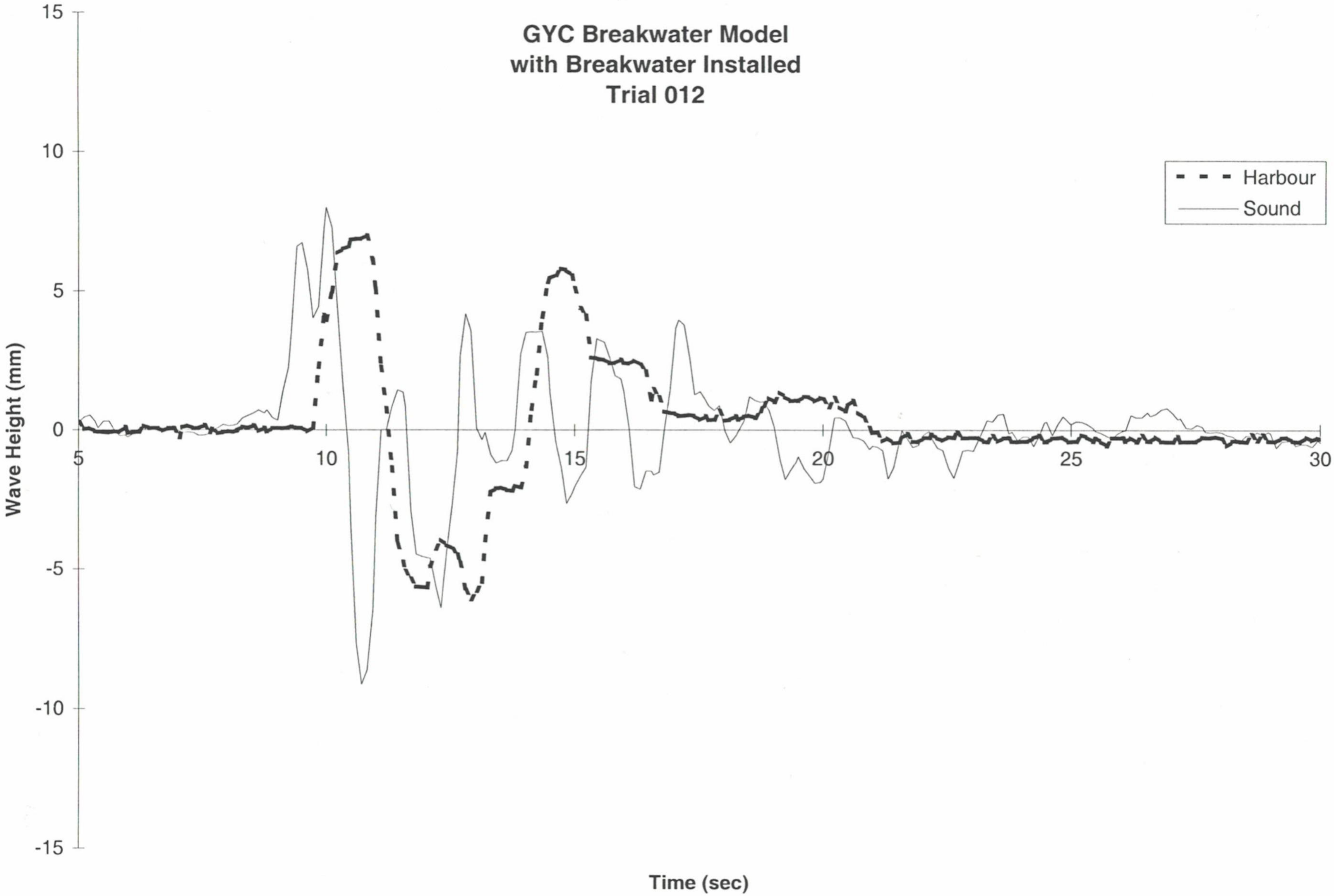
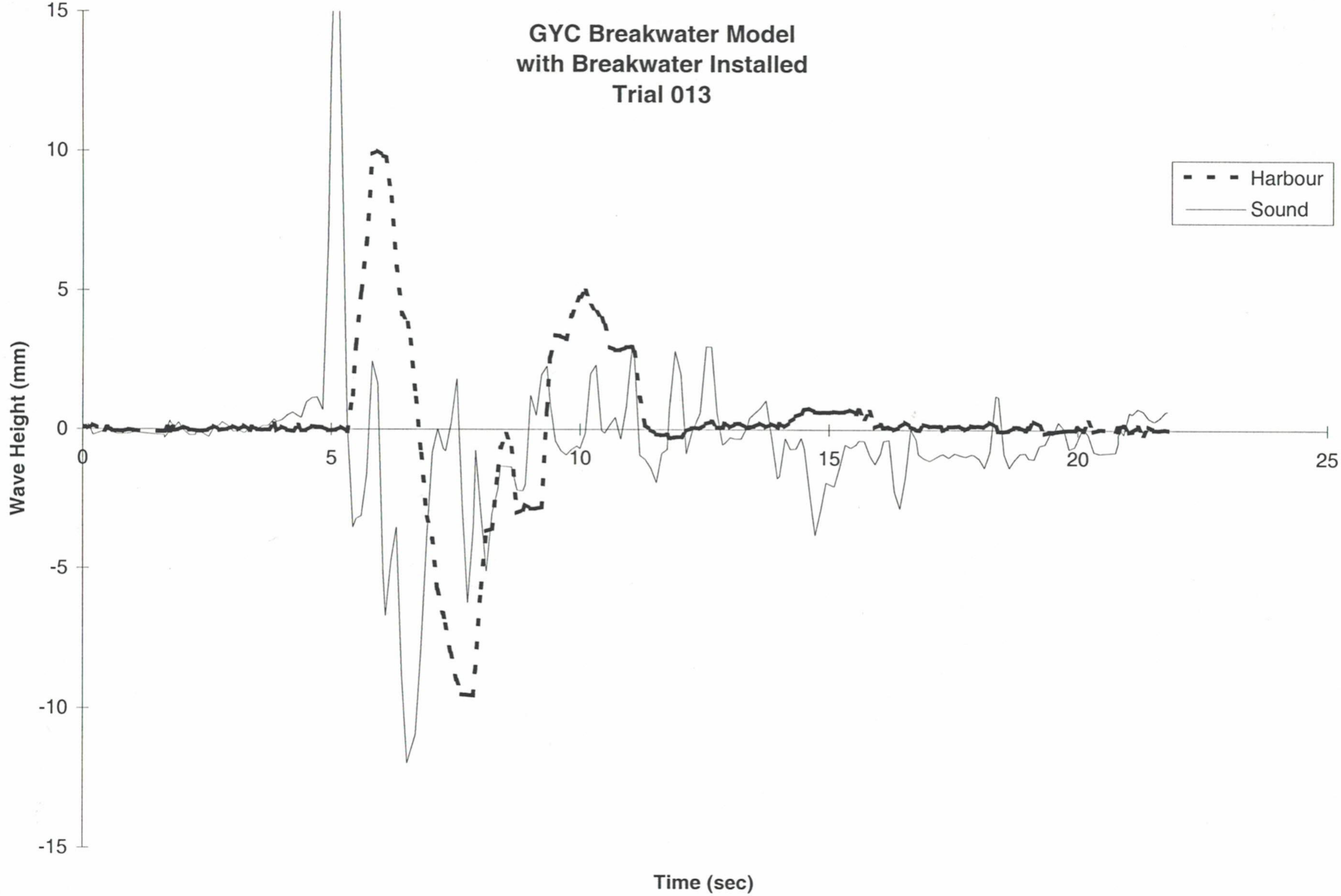
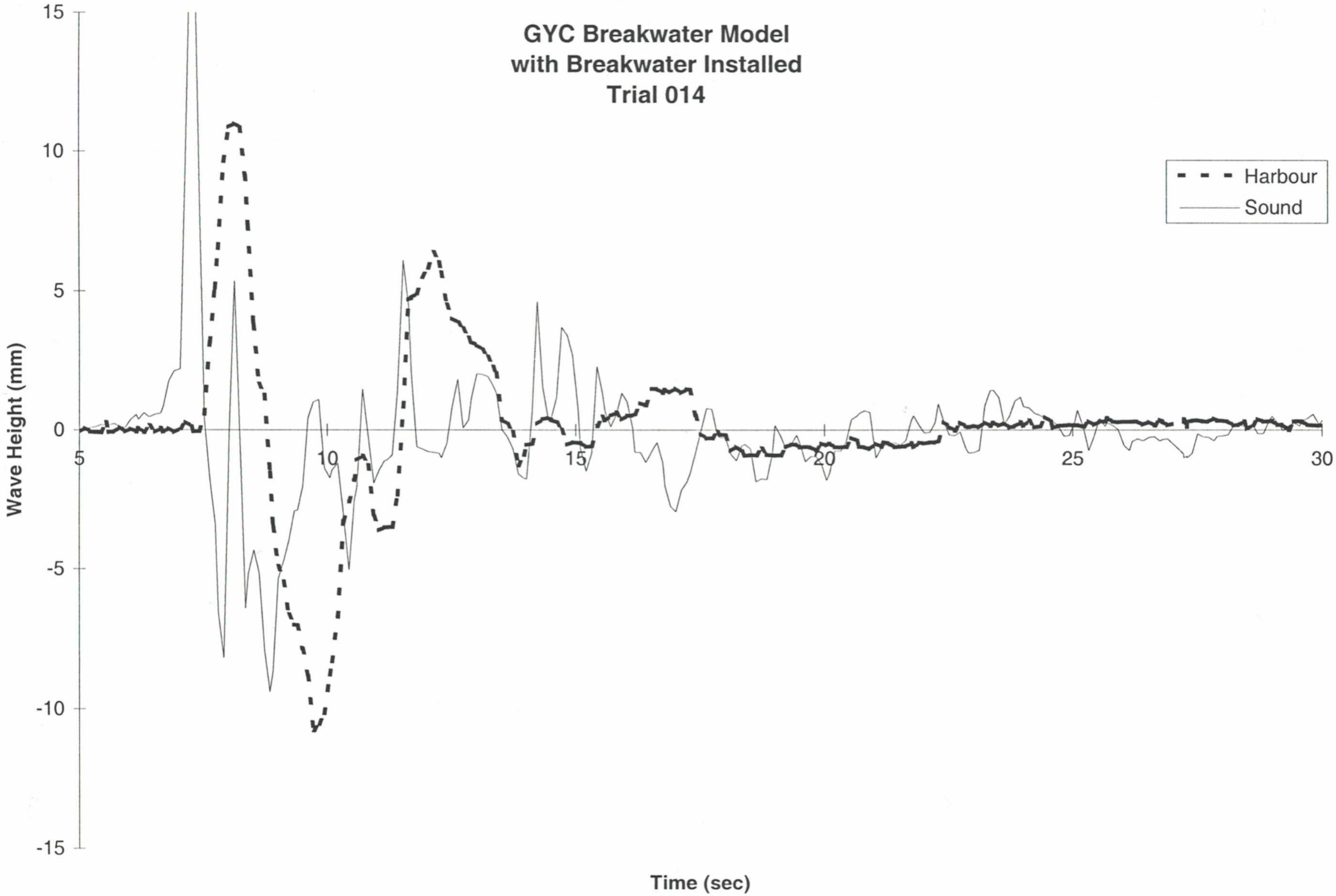
10
15
20
25
30



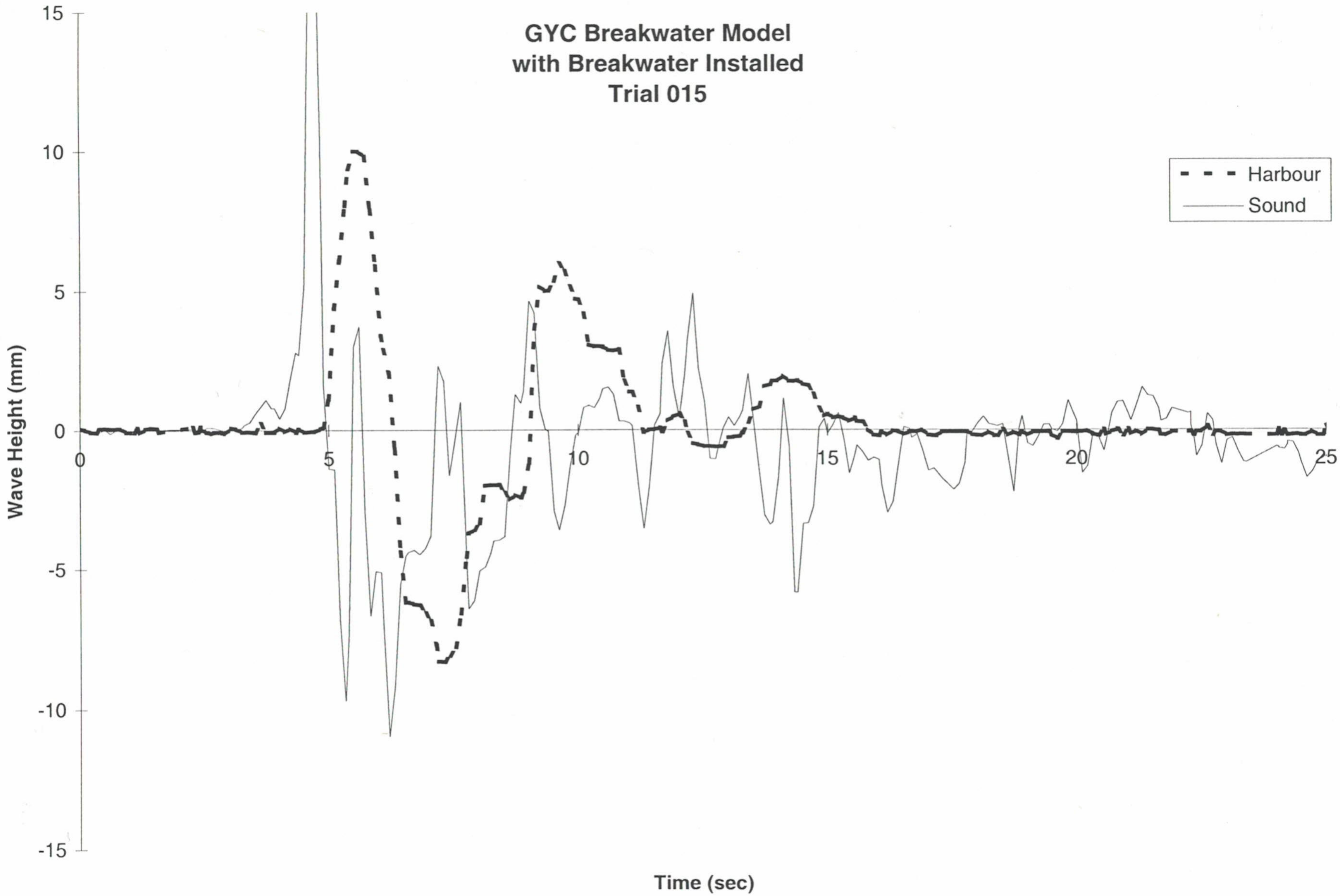
GYC Breakwater Model
with Breakwater Installed
Trial 011
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30

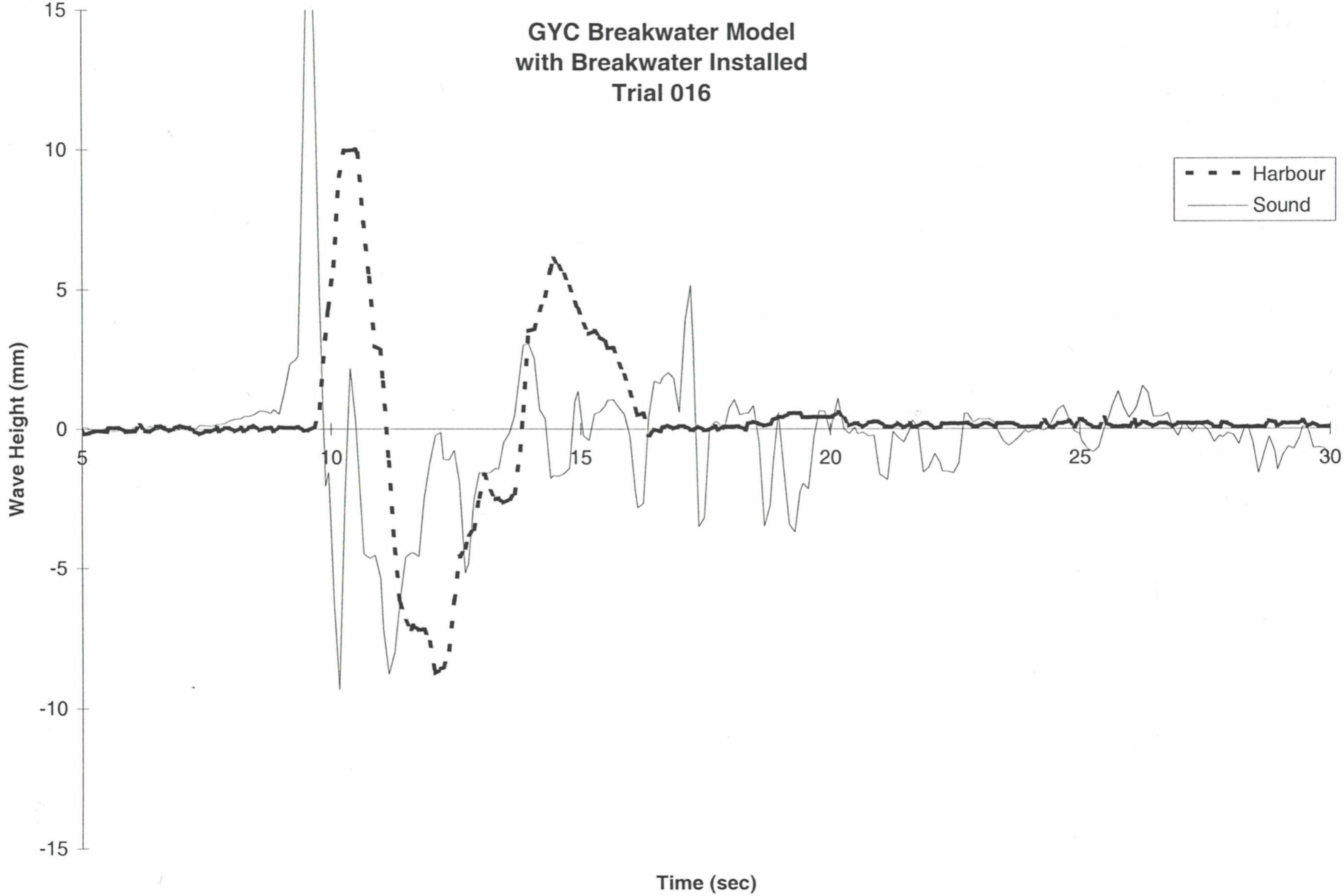

GYC Breakwater Model
with Breakwater Installed
Trial 012
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30

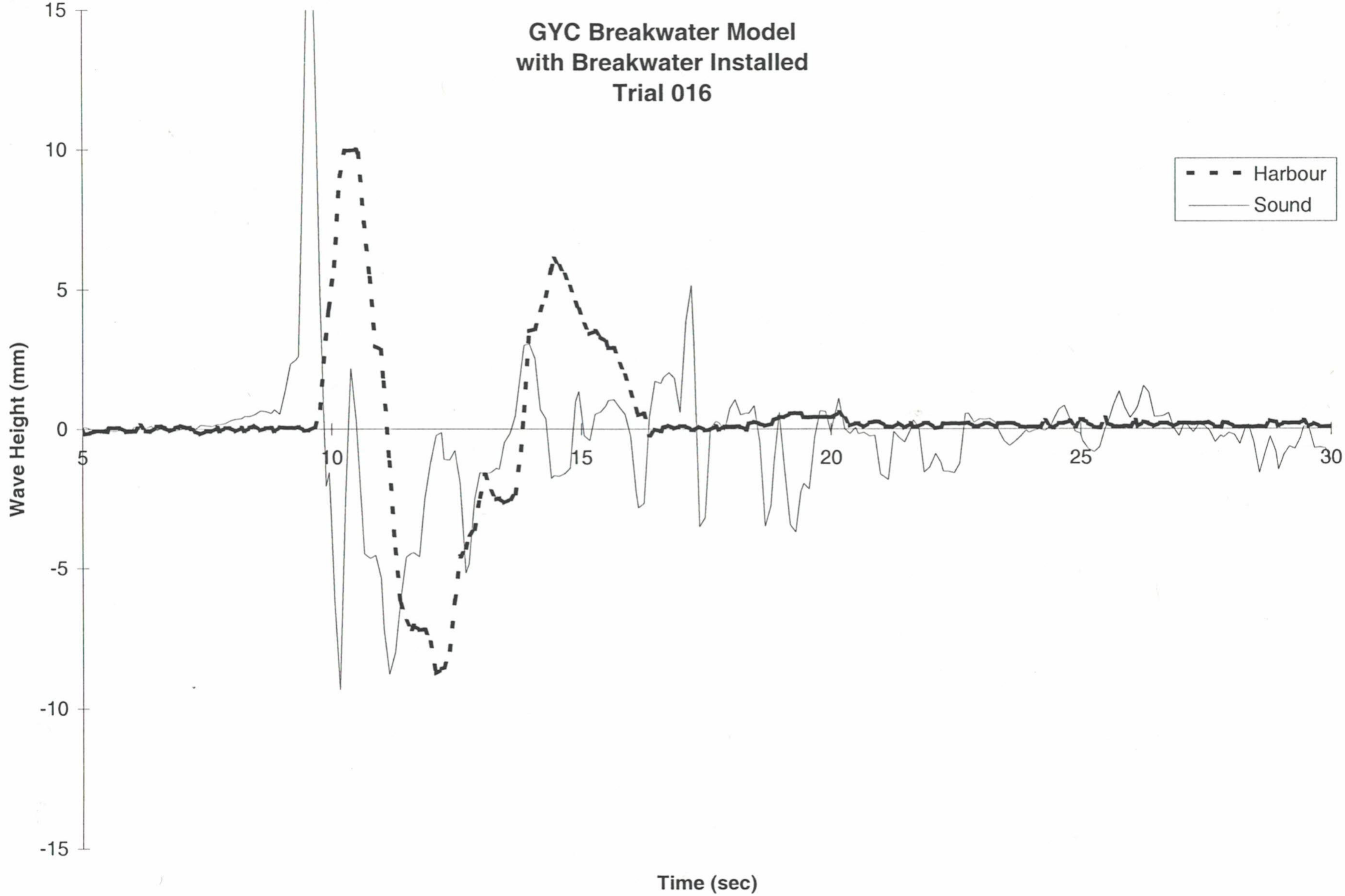

GYC Breakwater Model
with Breakwater Installed
Trial 013
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
0
5
10
15
20
25



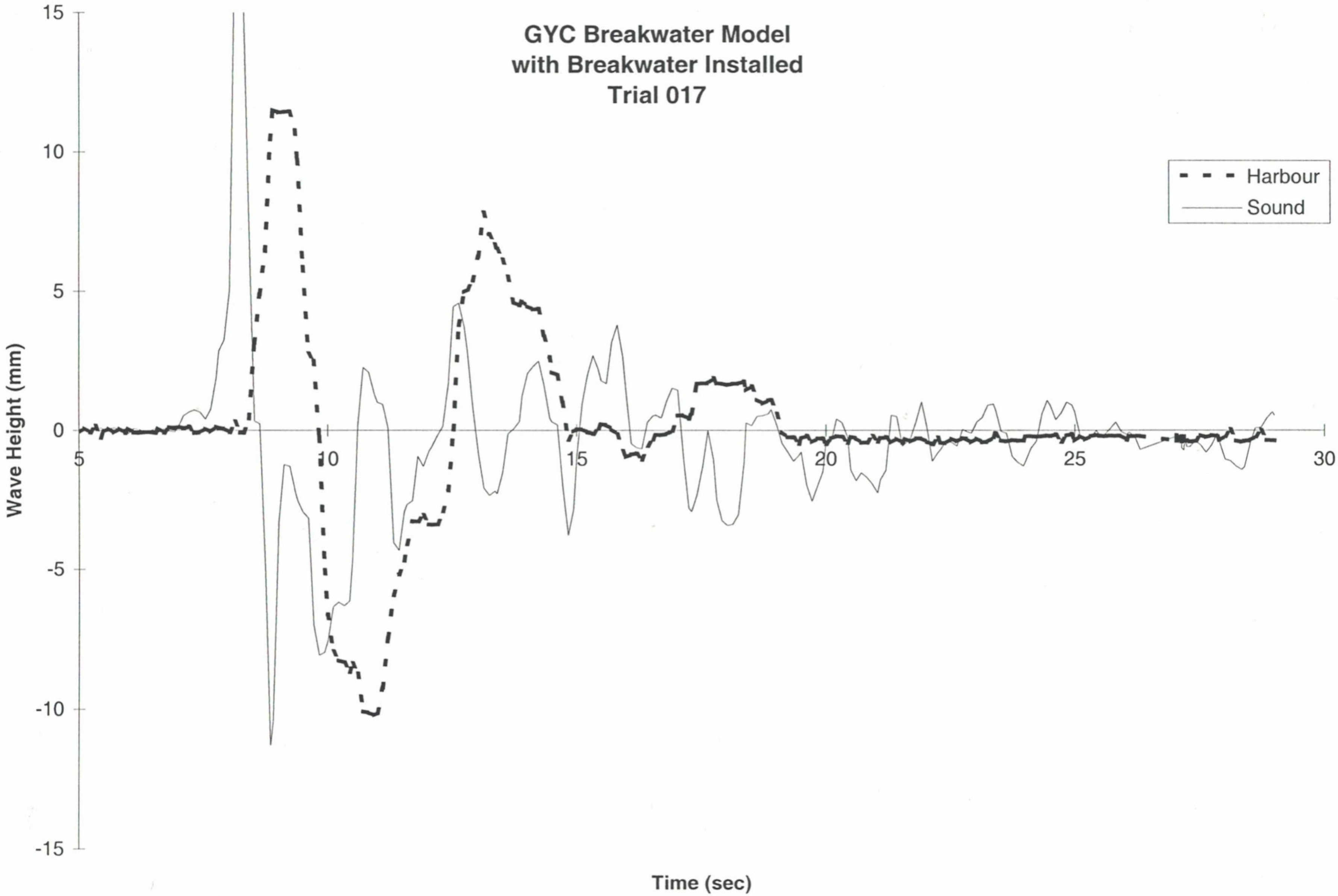
GYC Breakwater Model
with Breakwater Installed
Trial 014
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30


GYC Breakwater Model
with Breakwater Installed
Trial 015
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
0
5
10
15
20
25


GYC Breakwater Model
with Breakwater Installed
Trial 016
Harbour
Sound
Wave Height (mm)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30
Time (sec)



GYC Breakwater Model
with Breakwater Installed
Trial 016
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30



GYC Breakwater Model
with Breakwater Installed
Trial 017
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
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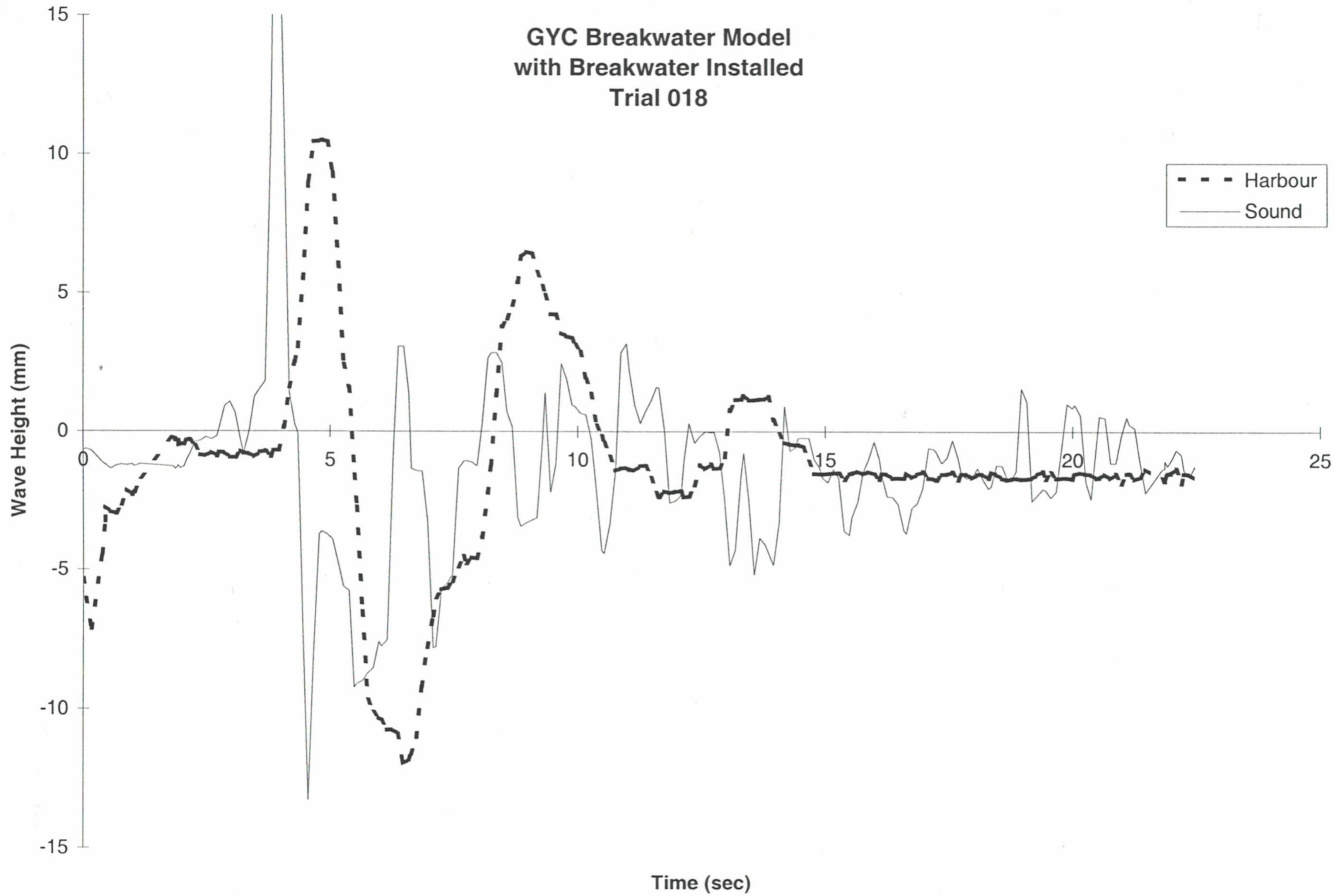
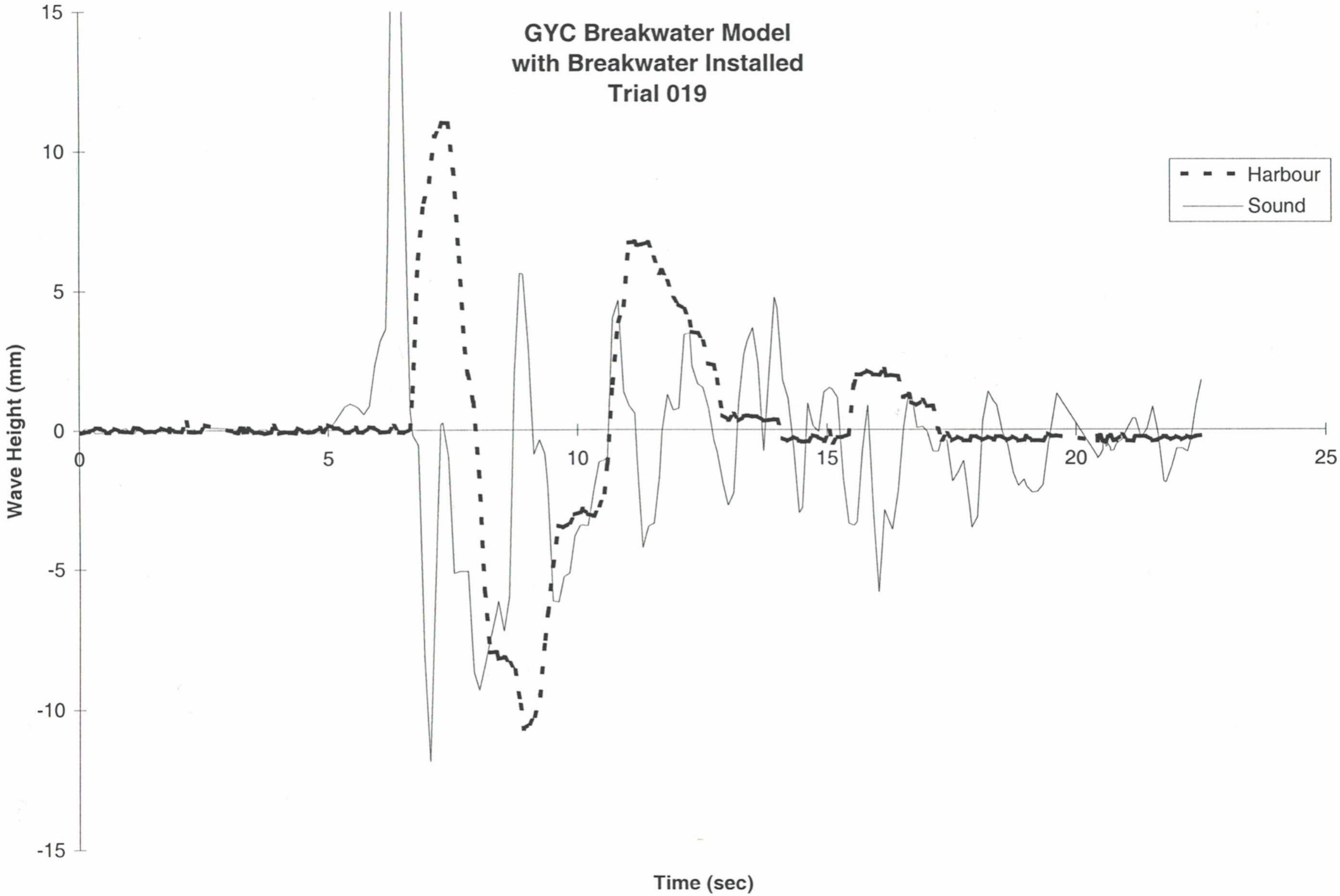
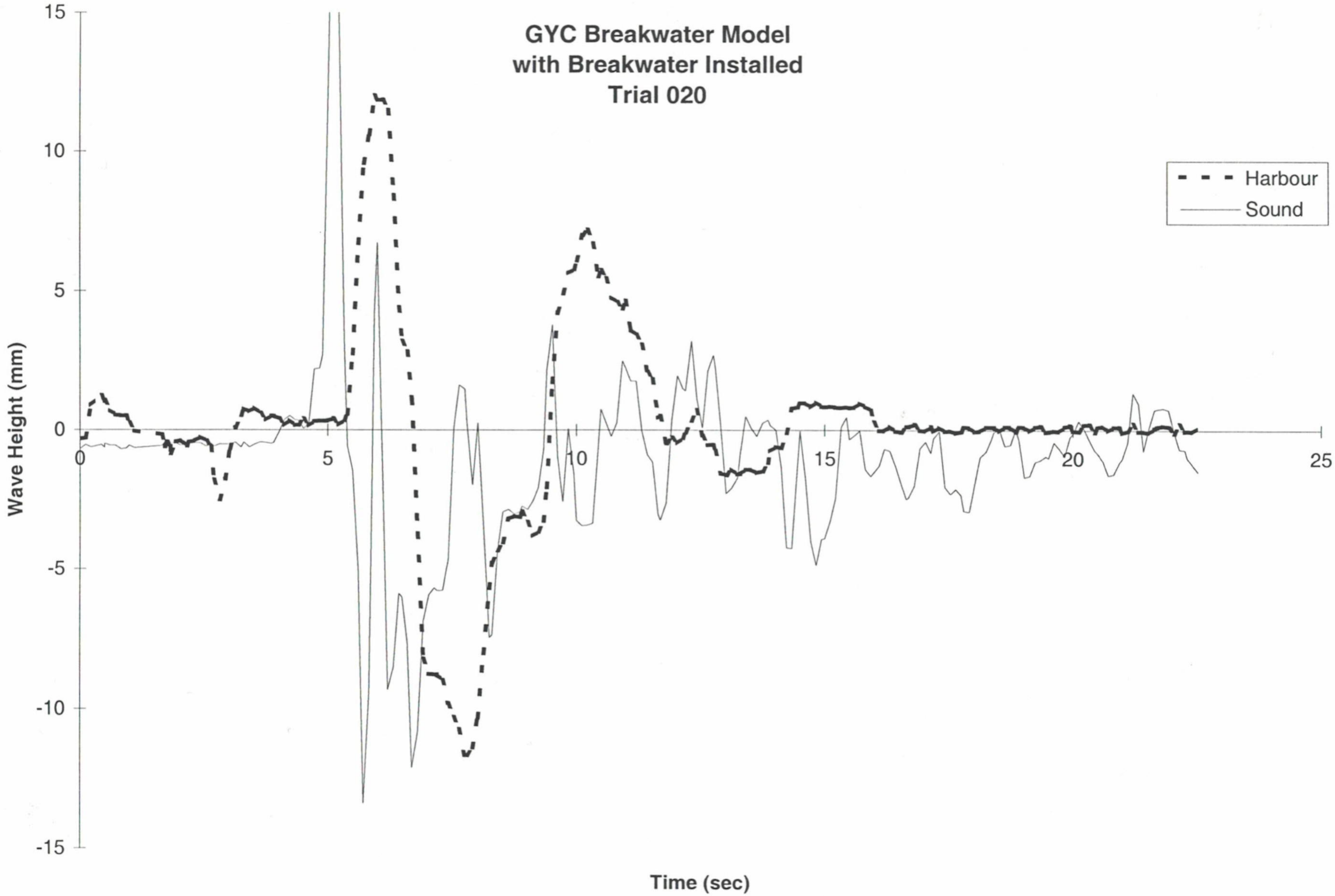
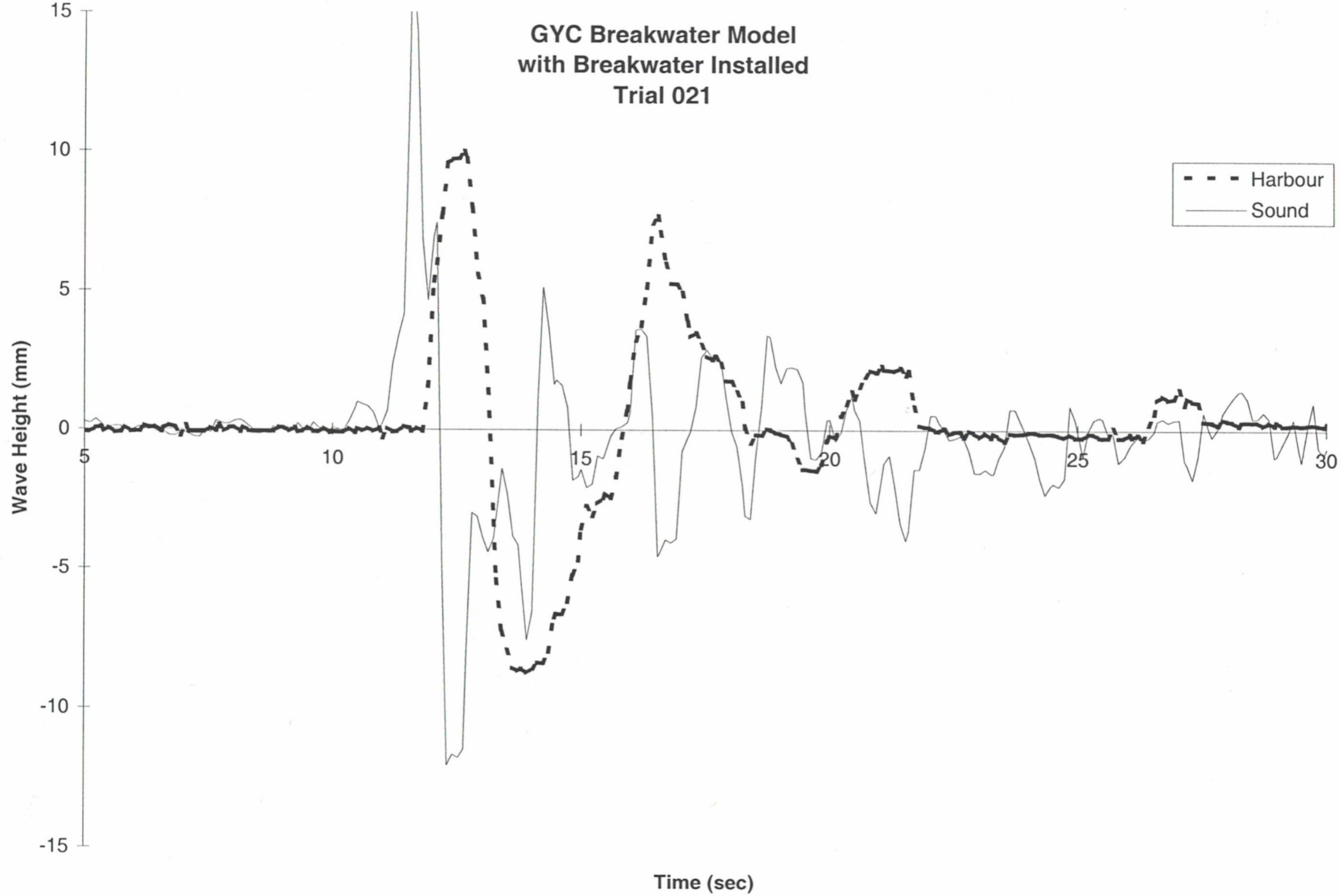
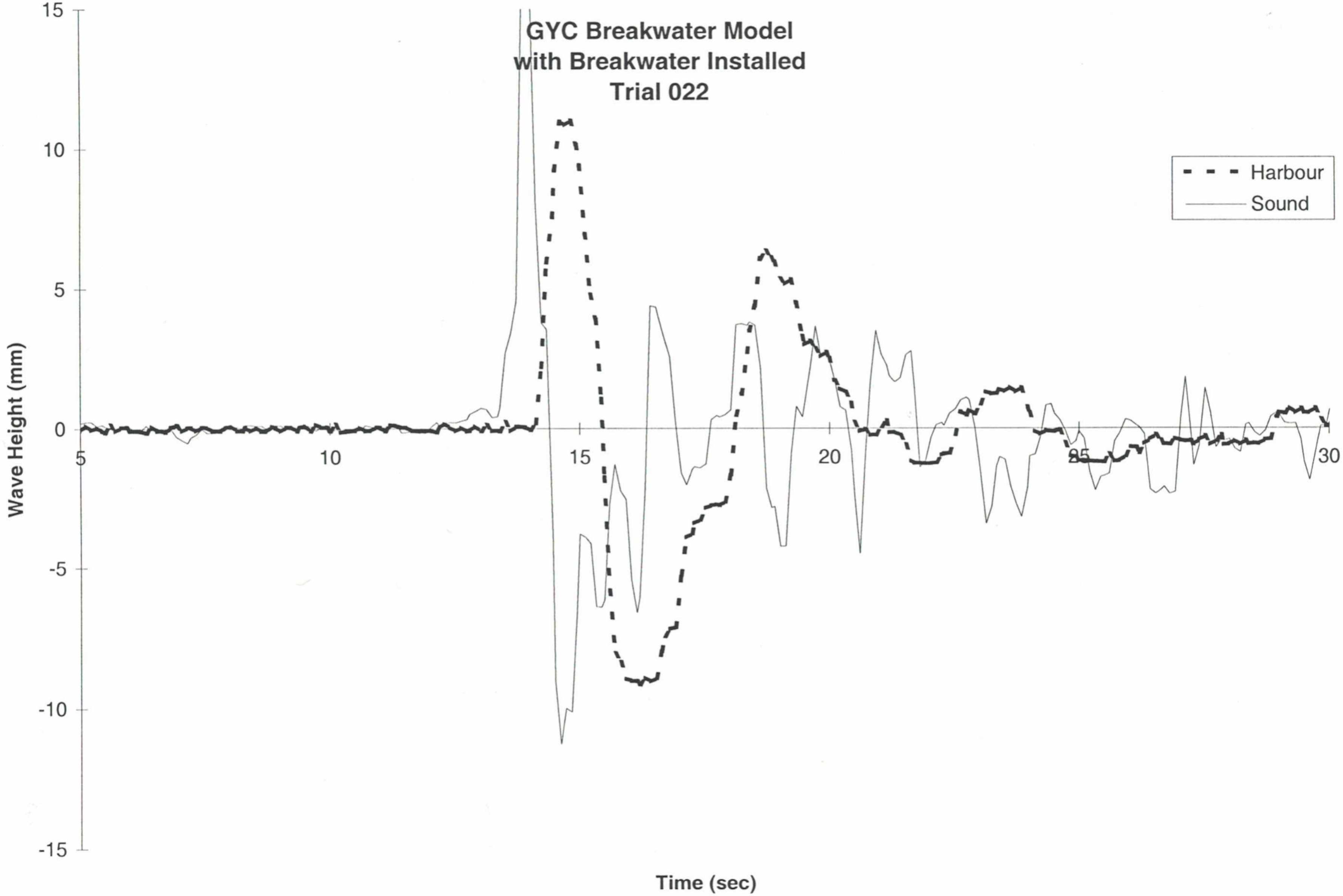
10
15
20
25
30

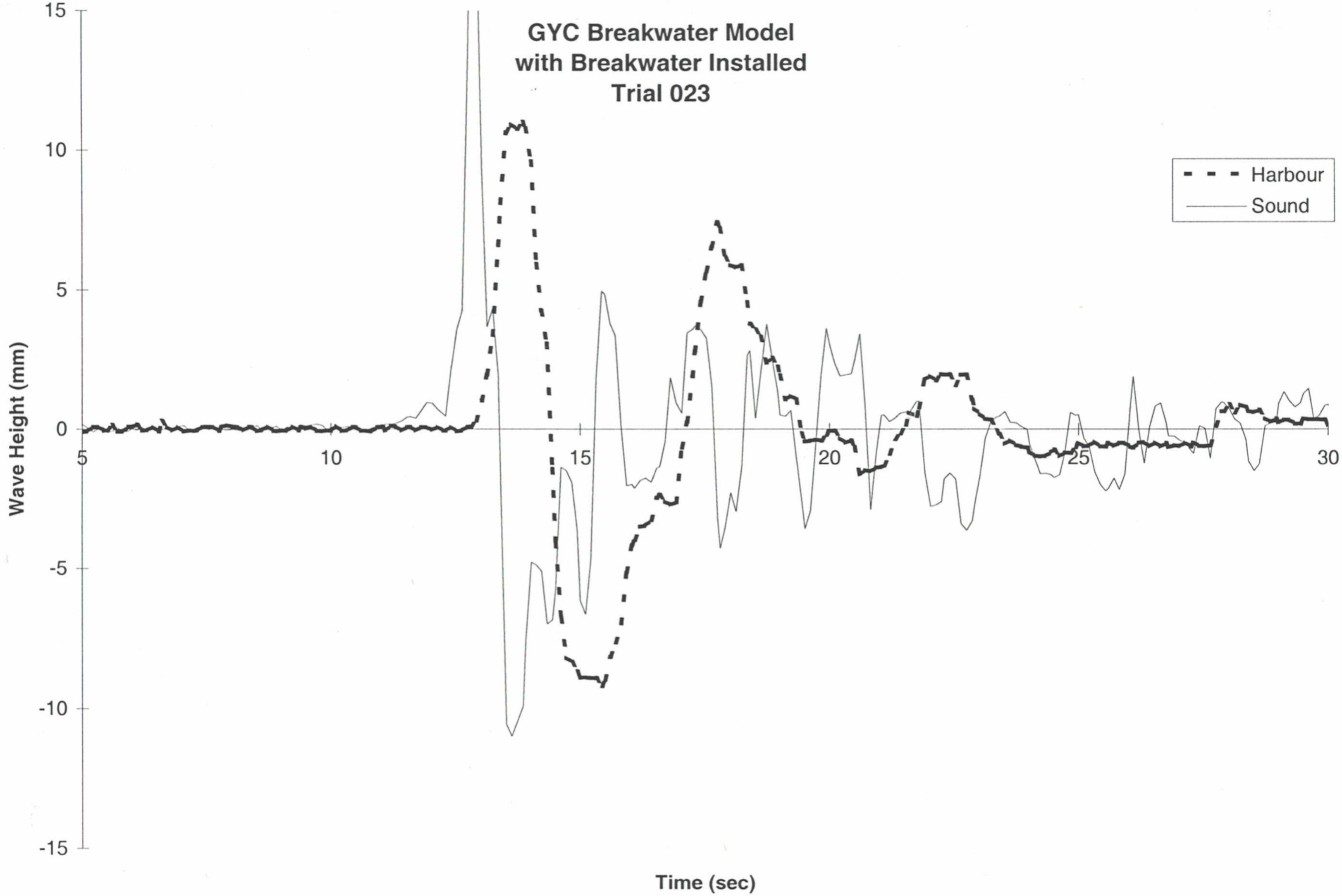

GYC Breakwater Model
with Breakwater Installed
Trial 018
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
0
5
10
15
20
25


GYC Breakwater Model
with Breakwater Installed
Trial 019
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
0
5
10
15
20
25

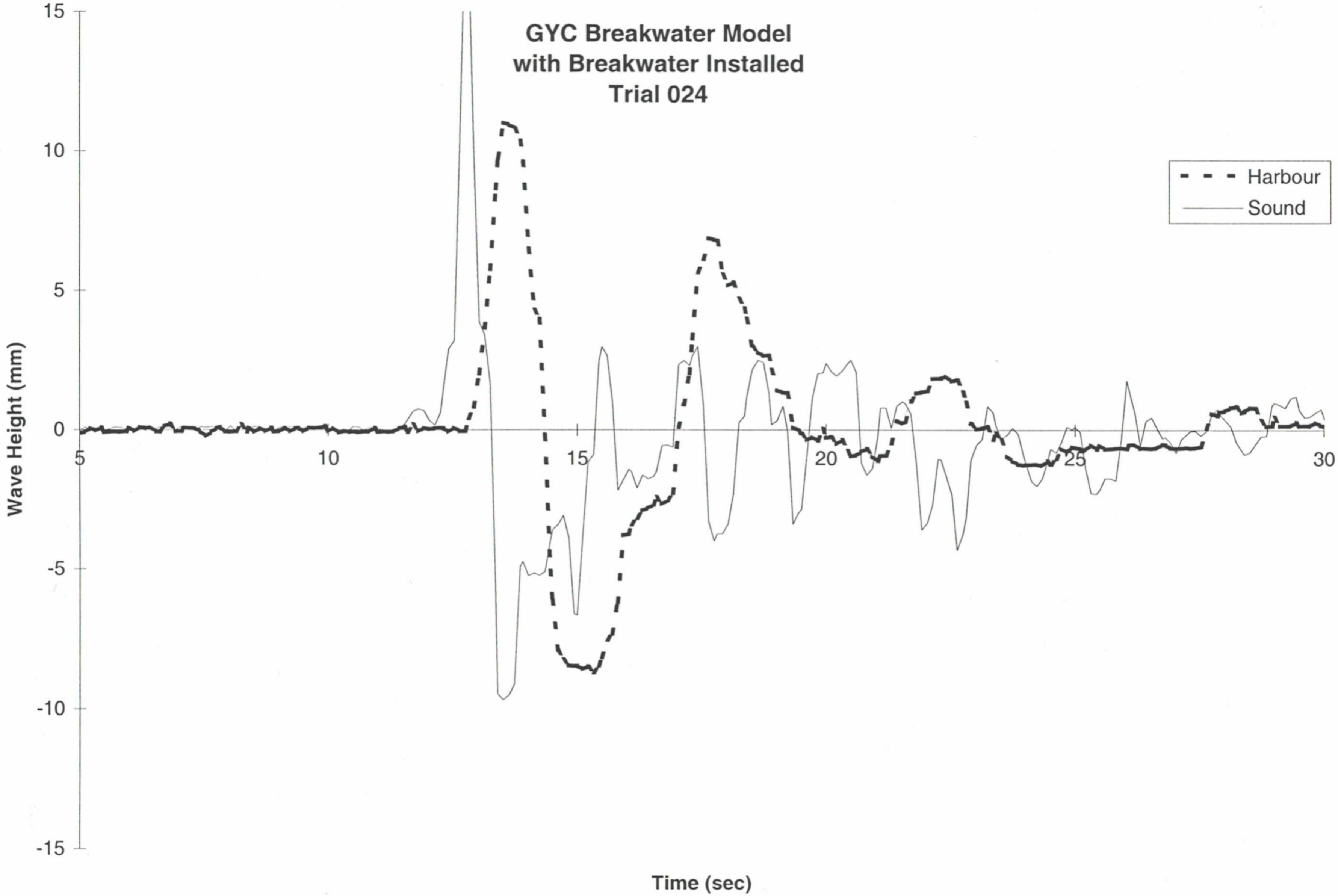

GYC Breakwater Model
with Breakwater Installed
Trial 020
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
0
5
10
15
20
25

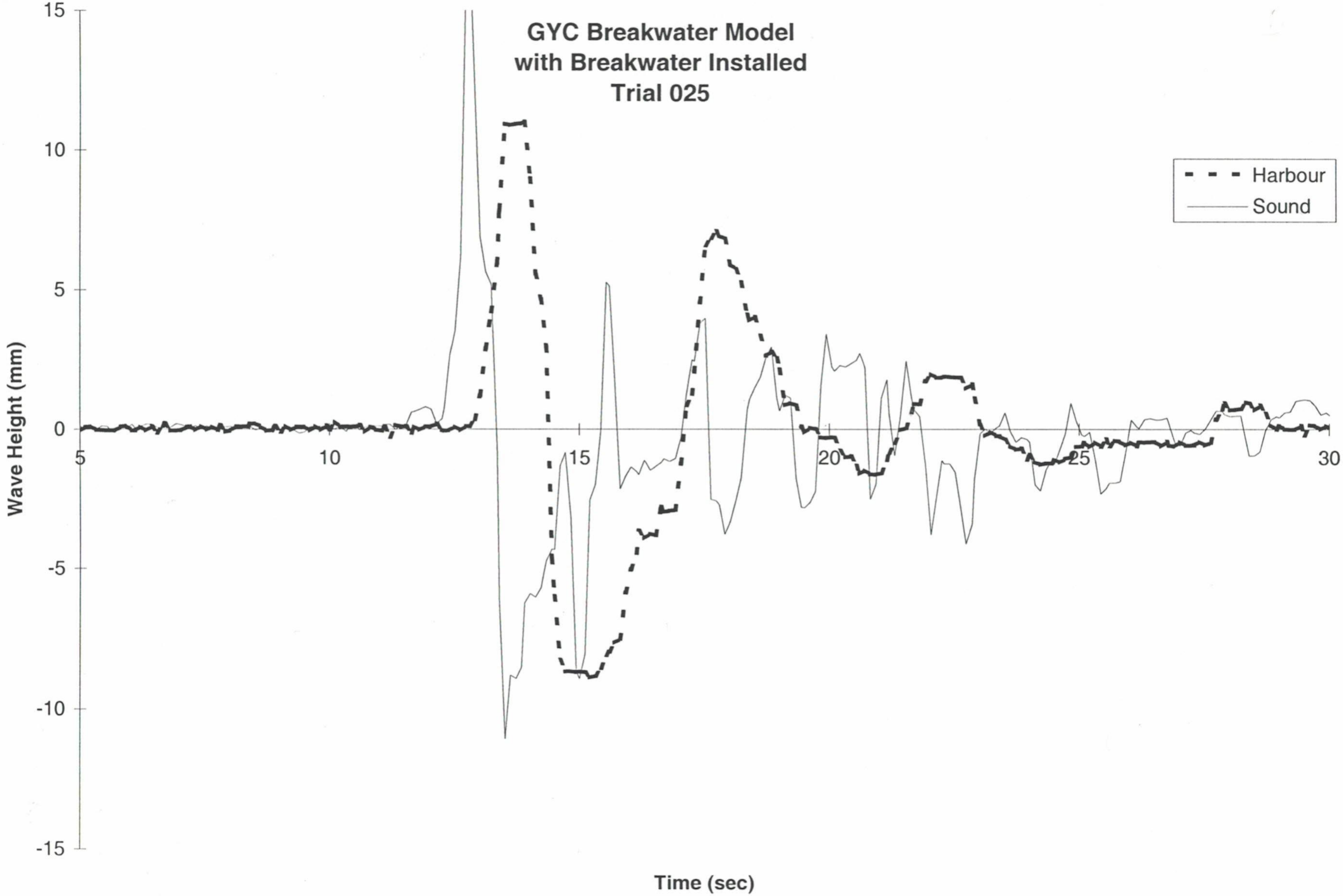

GYC Breakwater Model
with Breakwater Installed
Trial 021
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30


GYC Breakwater Model
with Breakwater Installed
Trial 022
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30

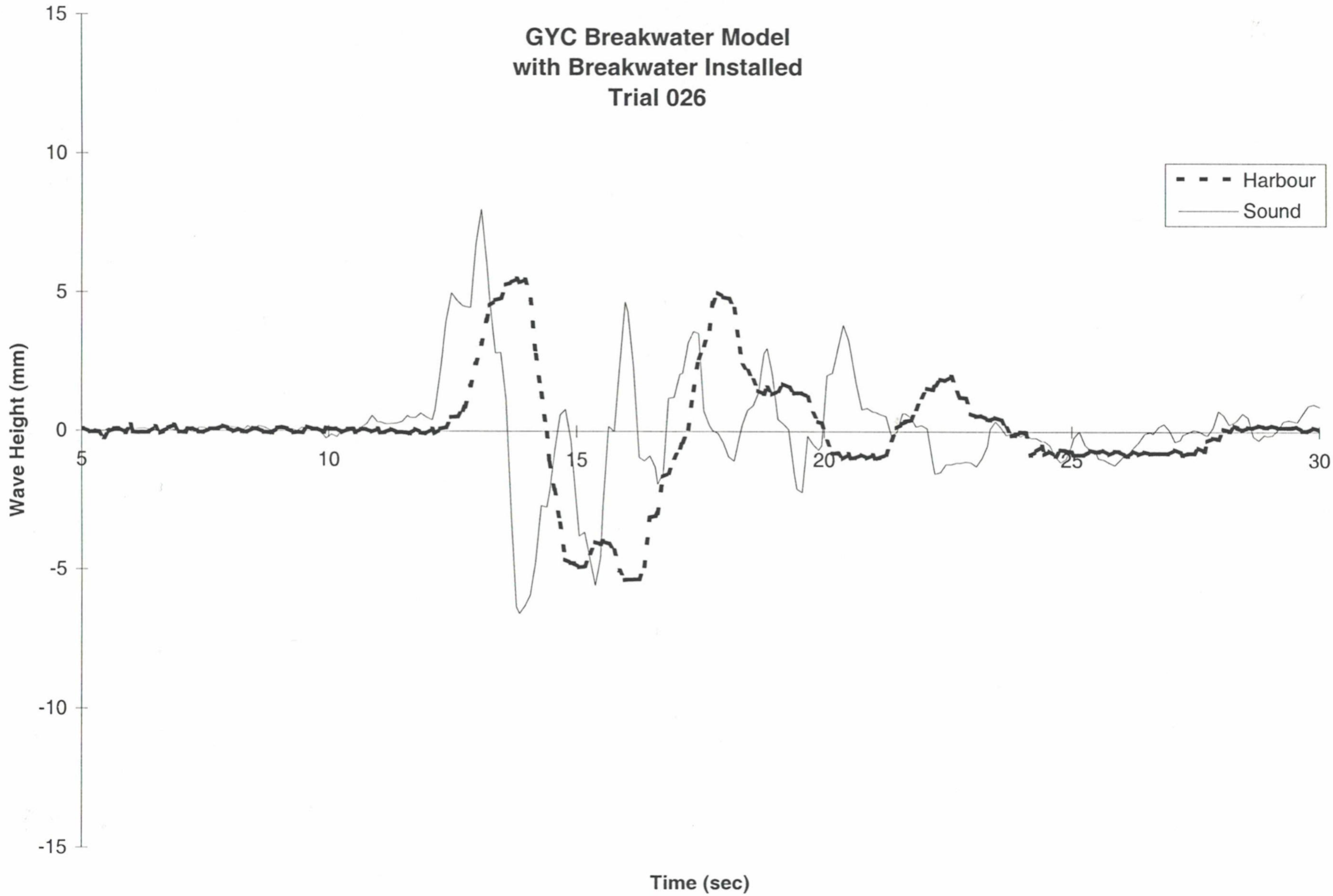


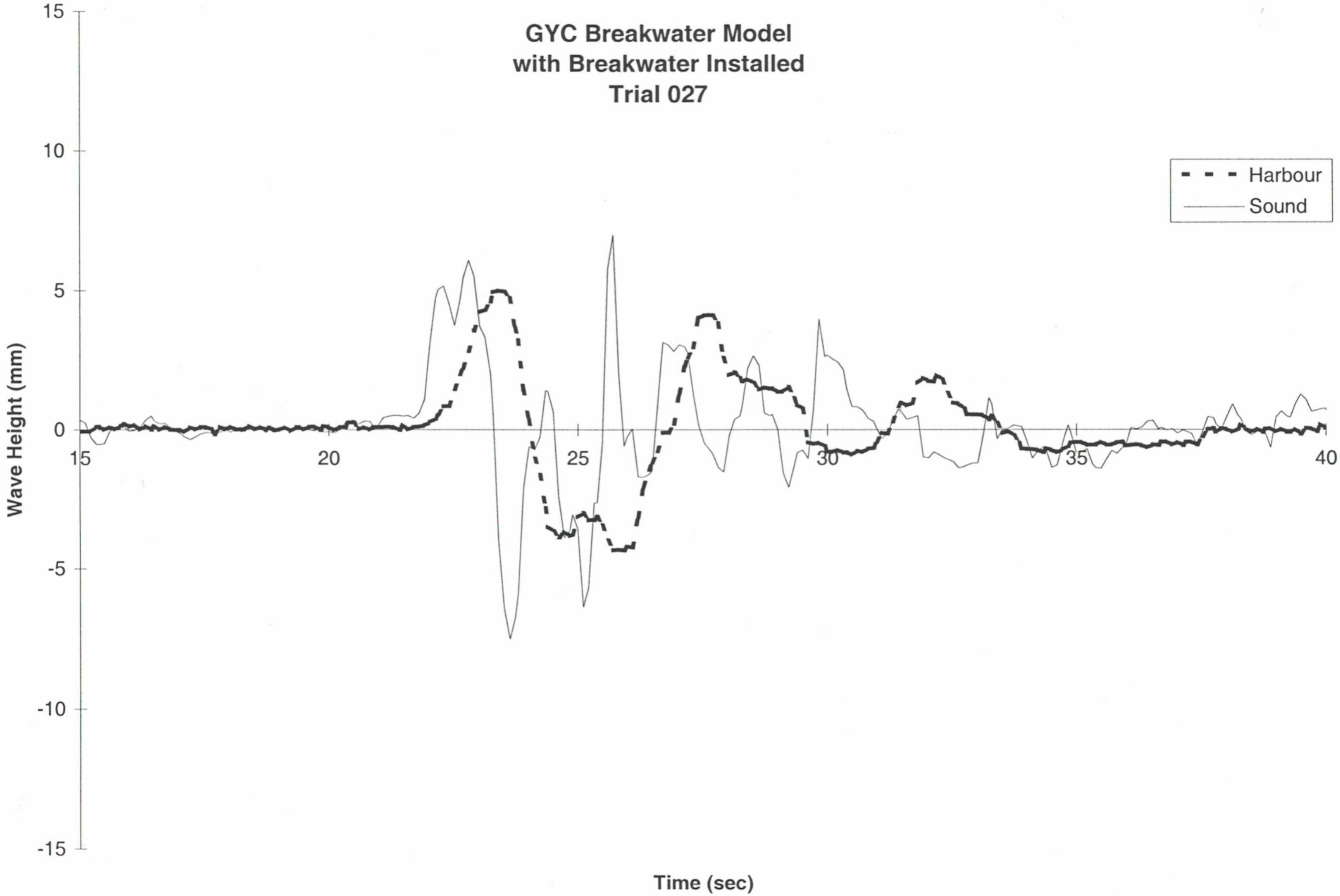
GYC Breakwater Model
with Breakwater Installed
Trial 023
Wave Height (mm)
Time (sec)
Harbour
Sound
15
10
5
0
-5
-10
-15
5
10
15
20
25
30

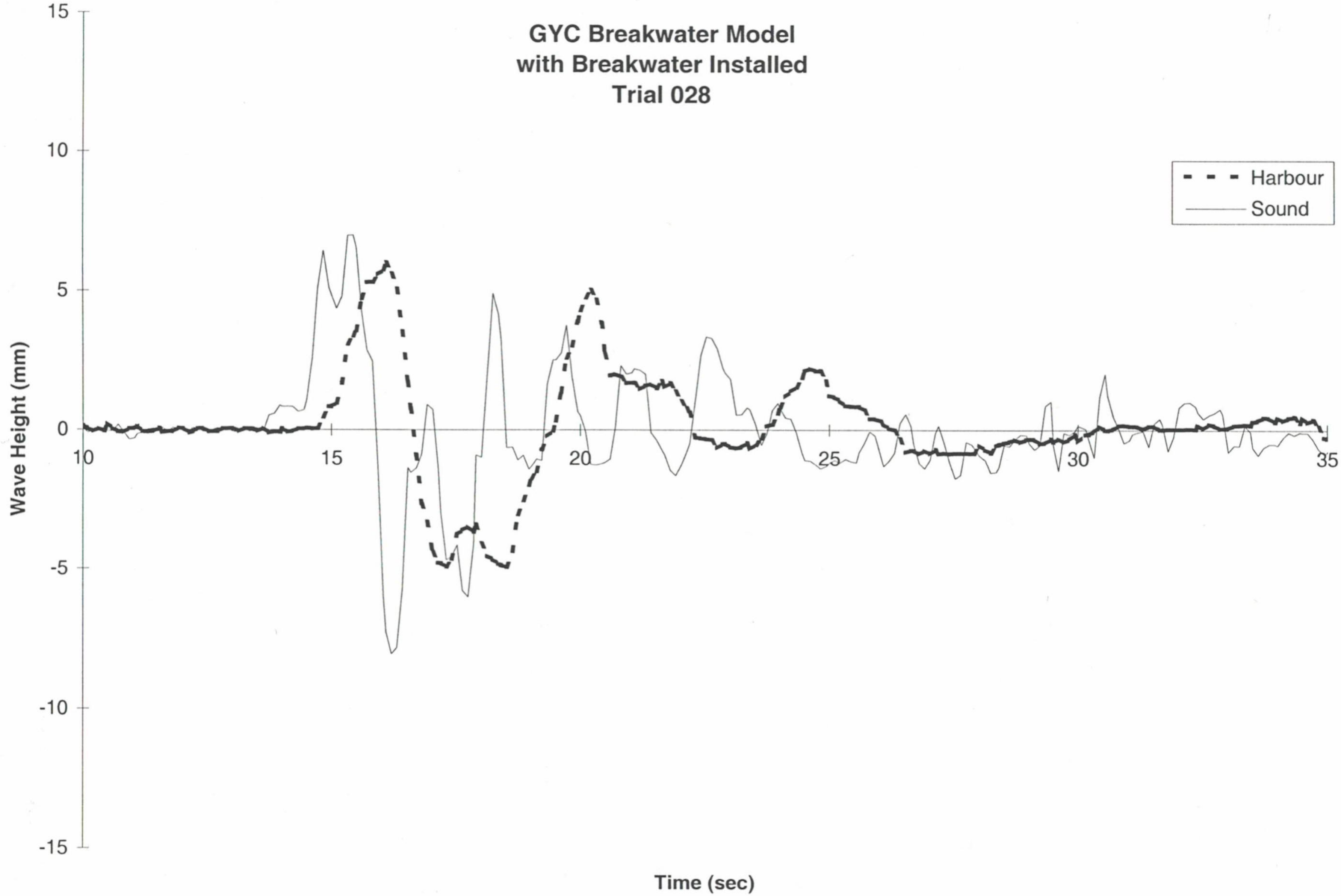

GYC Breakwater Model
with Breakwater Installed
Trial 024
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30



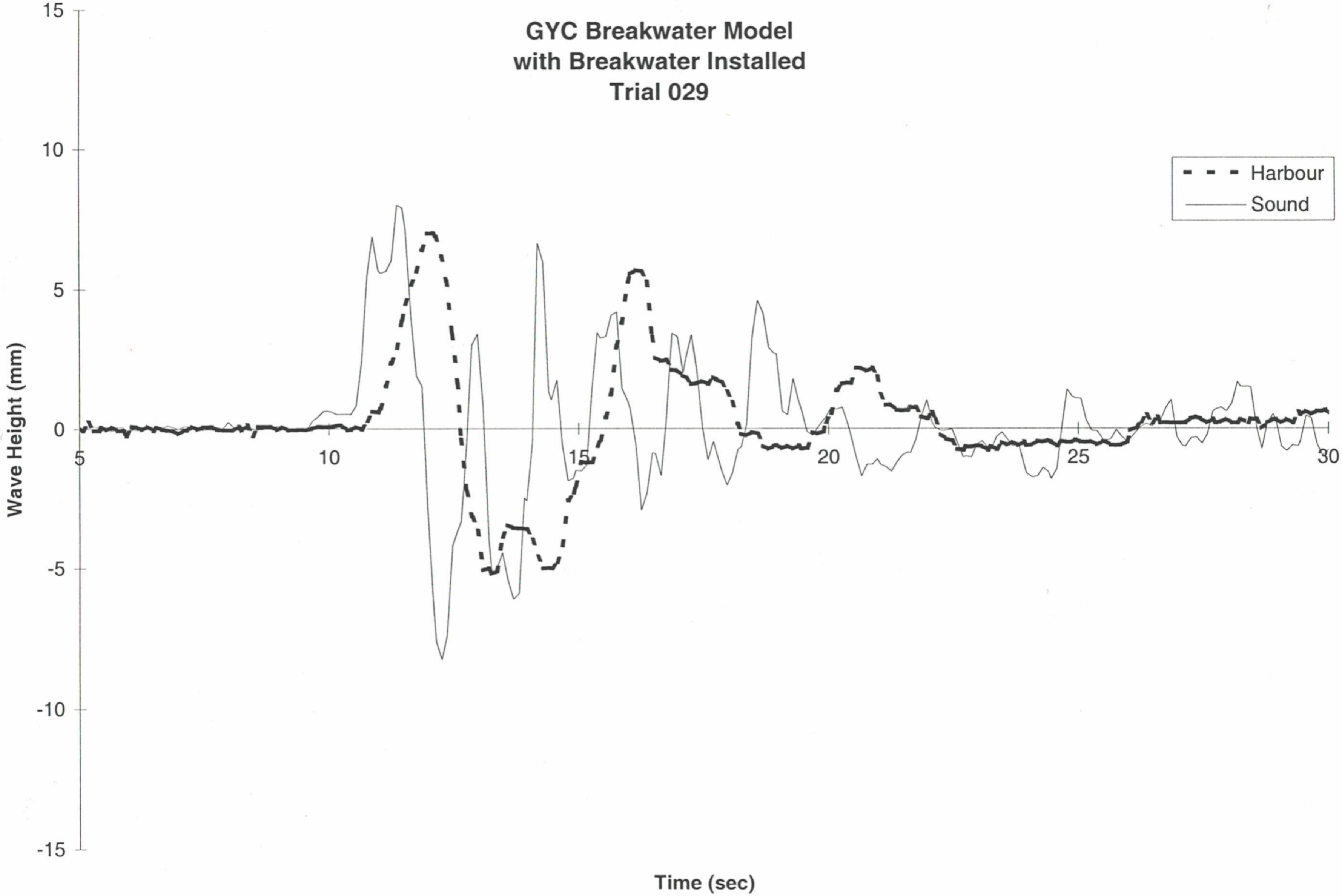
GYC Breakwater Model
with Breakwater Installed
Trial 025
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30


GYC Breakwater Model
with Breakwater Installed
Trial 026
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30

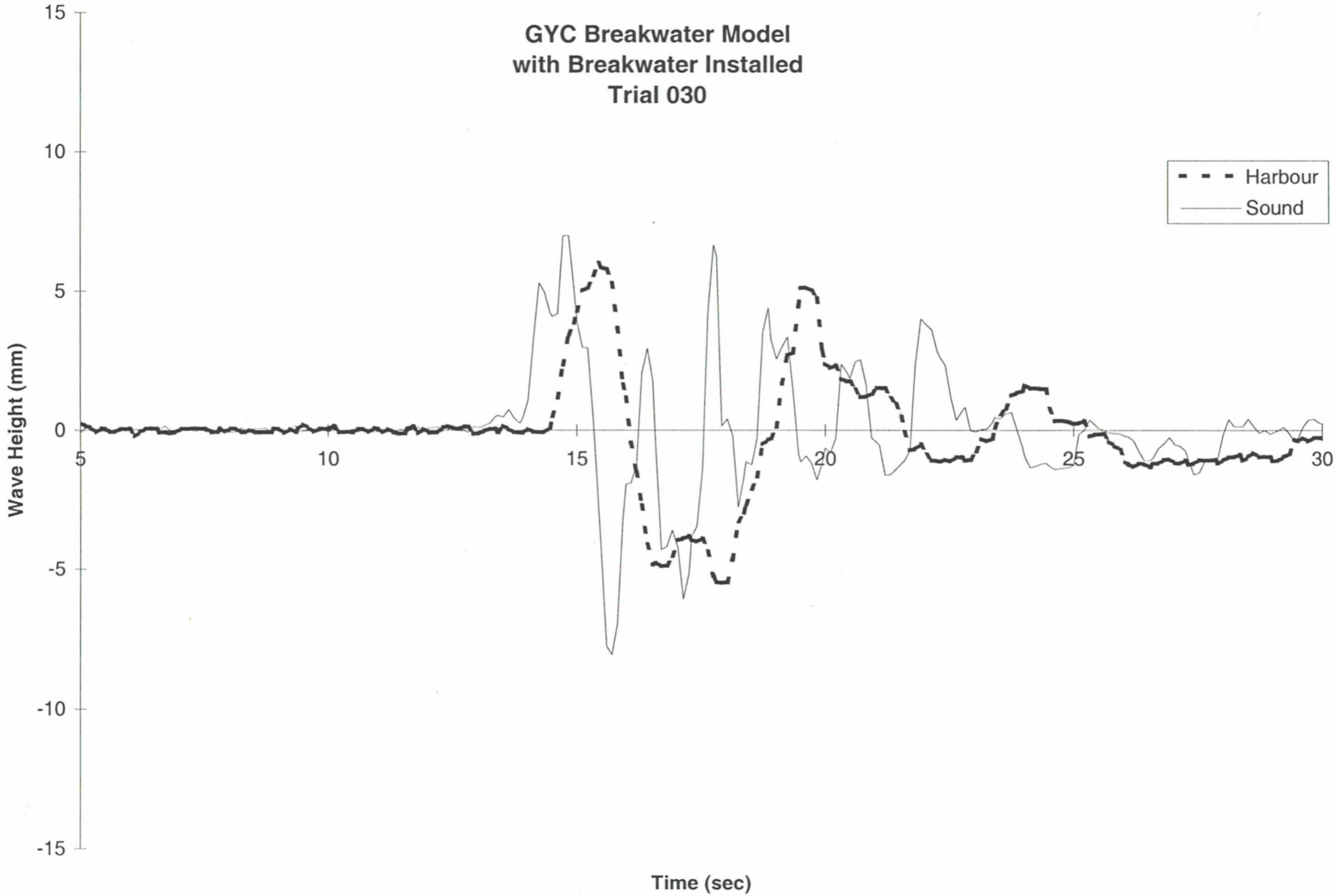

GYC Breakwater Model
with Breakwater Installed
Trial 027
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
15
20
25
30
35
40

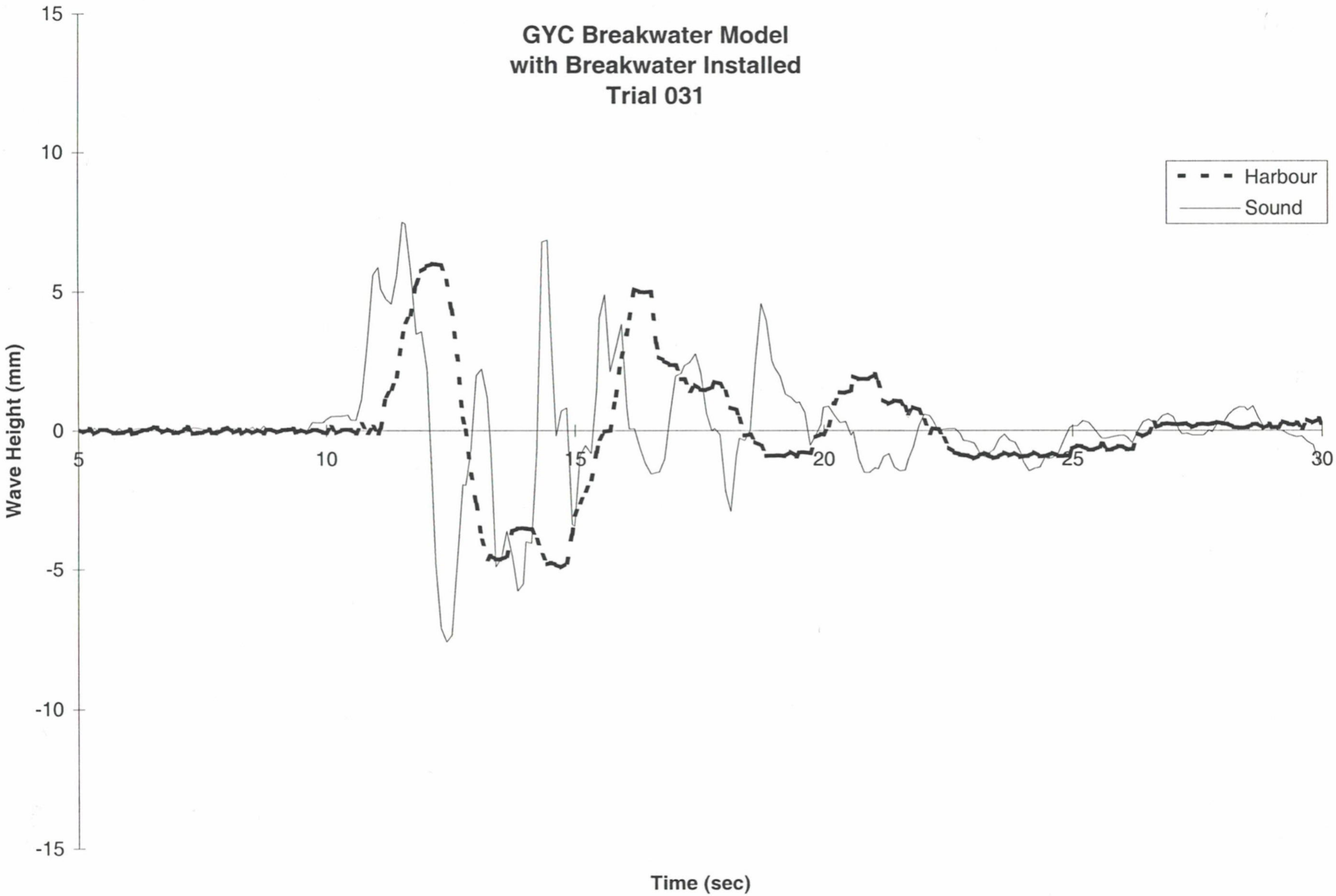


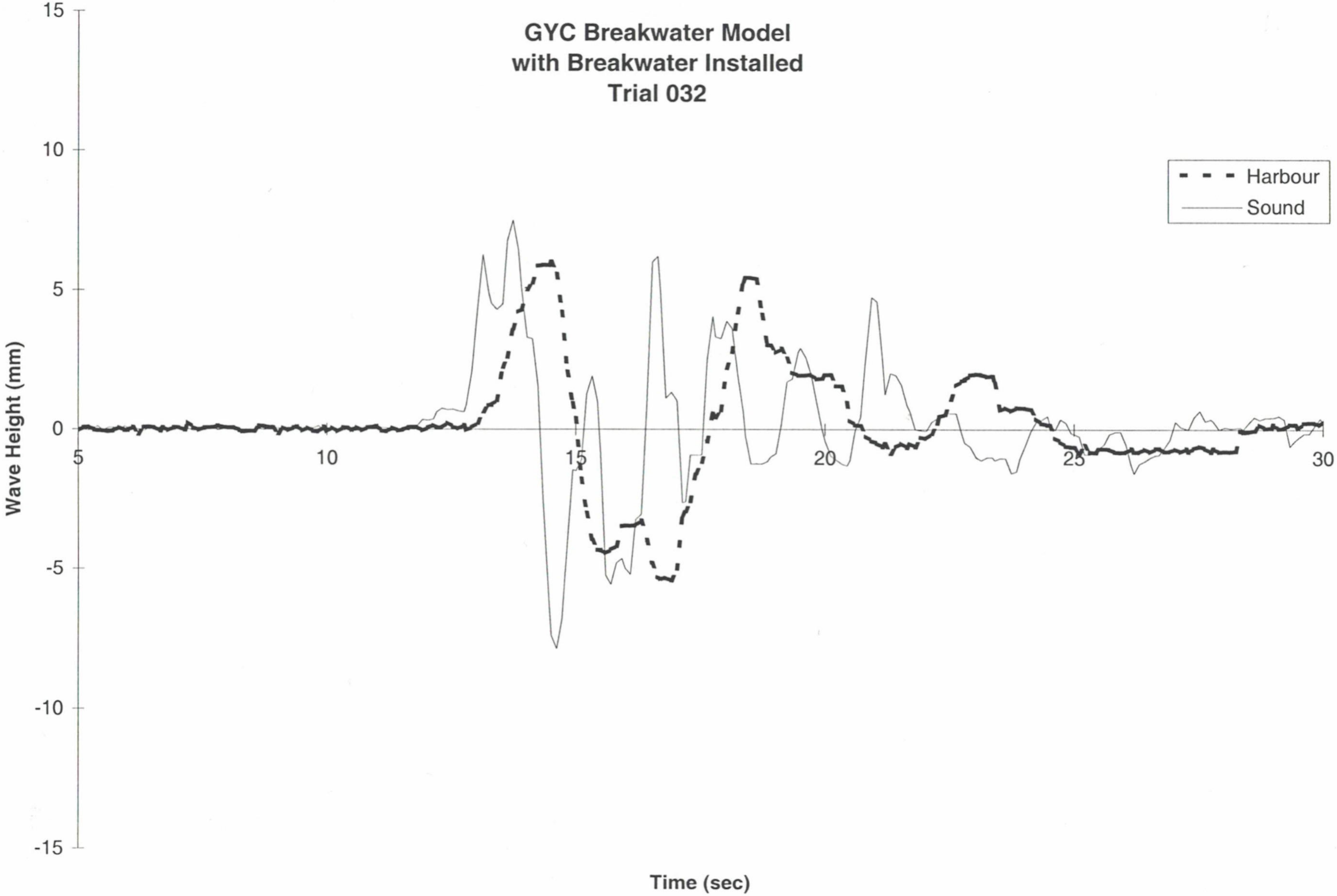
GYC Breakwater Model
with Breakwater Installed
Trial 028
Harbour
Sound
Wave Height (mm)
15
10
5
0
-5
-10
-15
10
15
20
25
30
35
Time (sec)



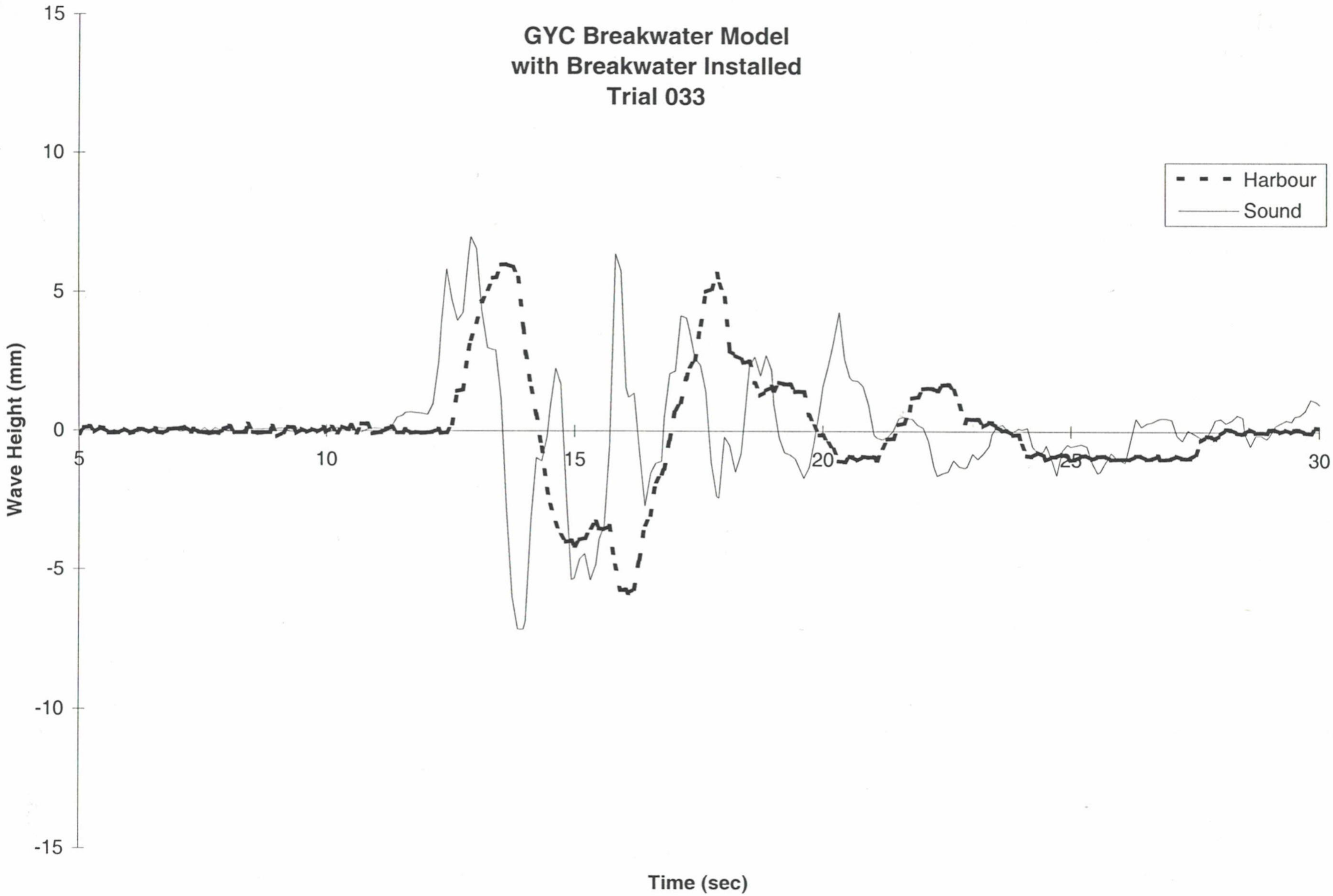
GYC Breakwater Model
with Breakwater Installed
Trial 029
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30

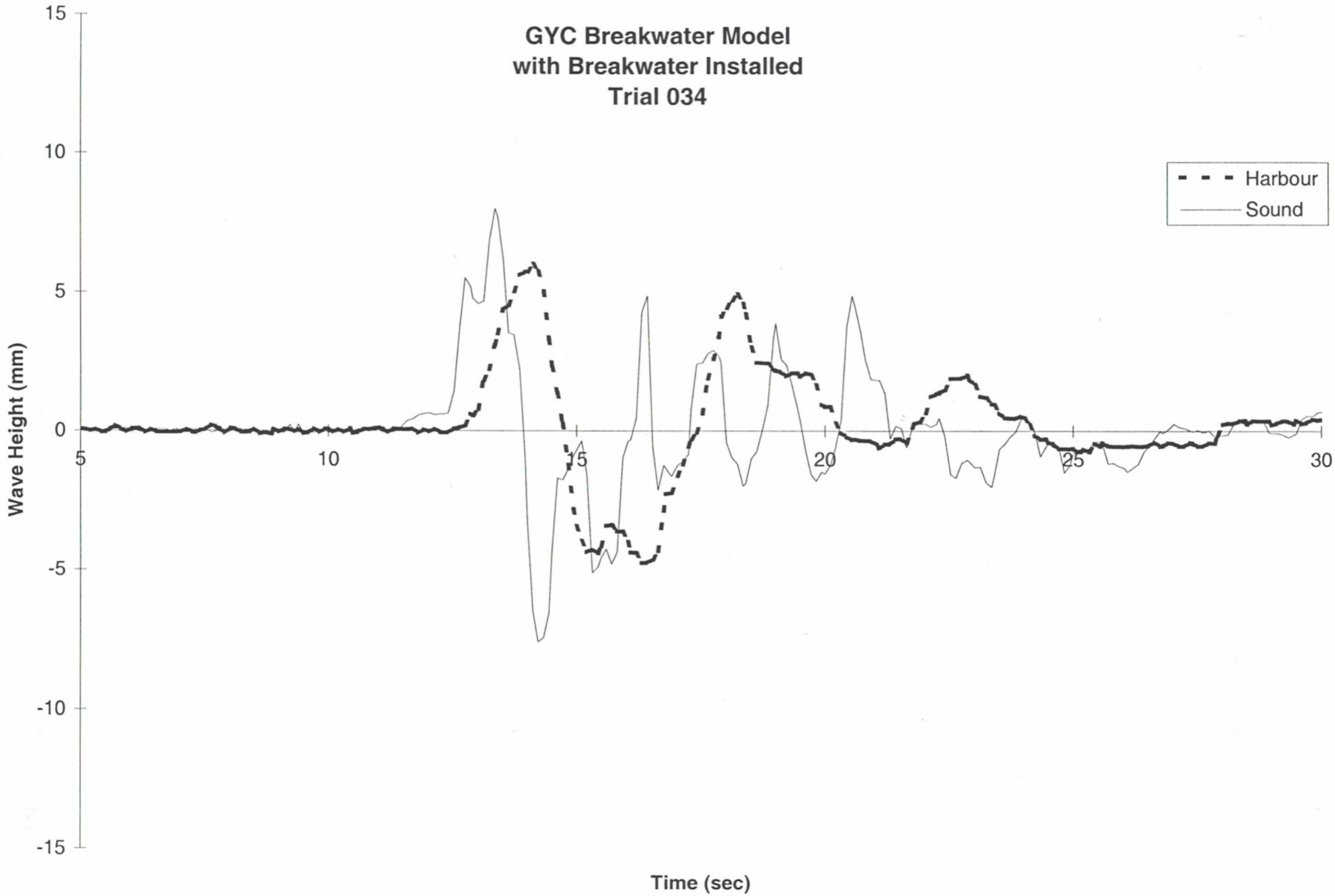

GYC Breakwater Model
with Breakwater Installed
Trial 030
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30

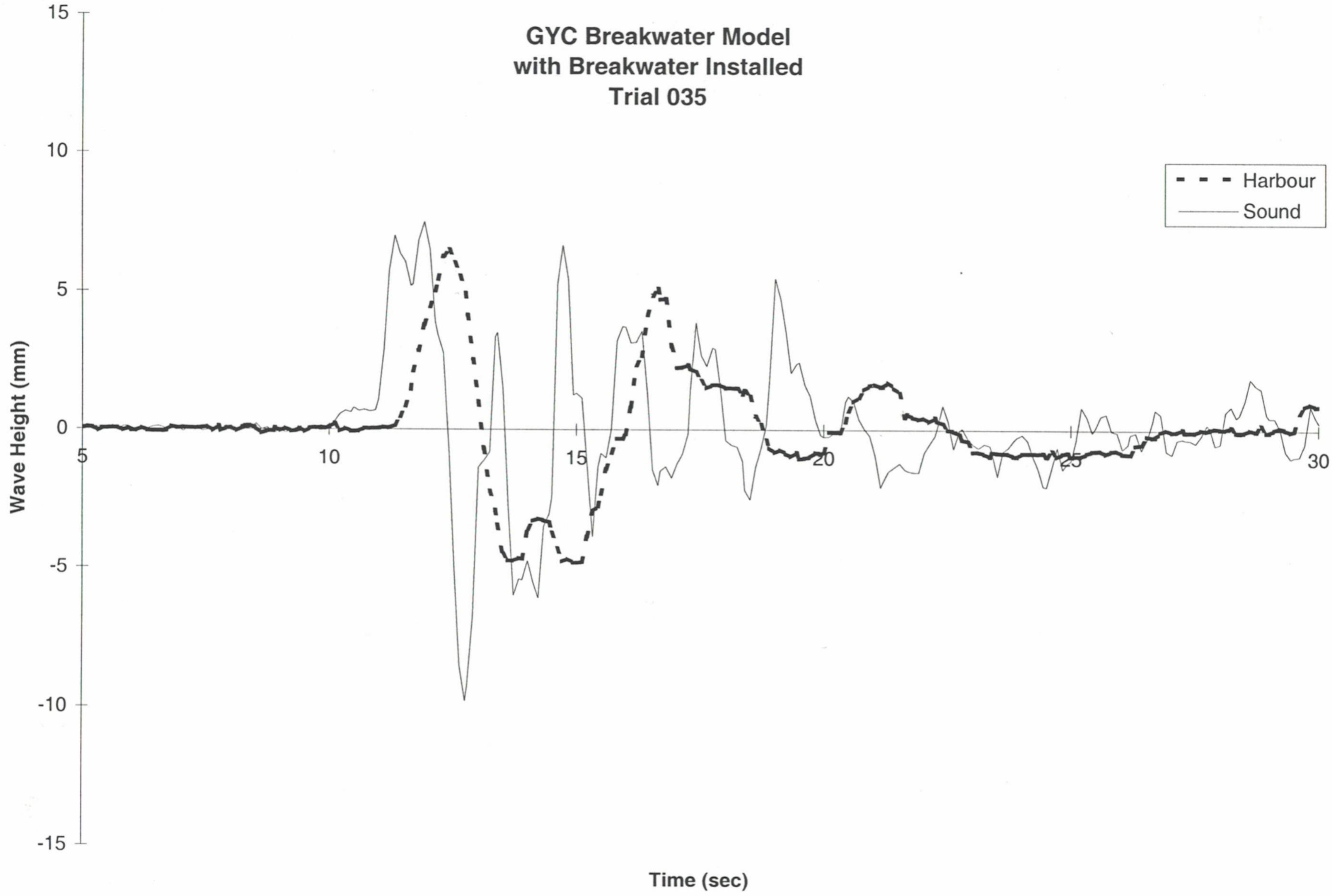

GYC Breakwater Model
with Breakwater Installed
Trial 031
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30

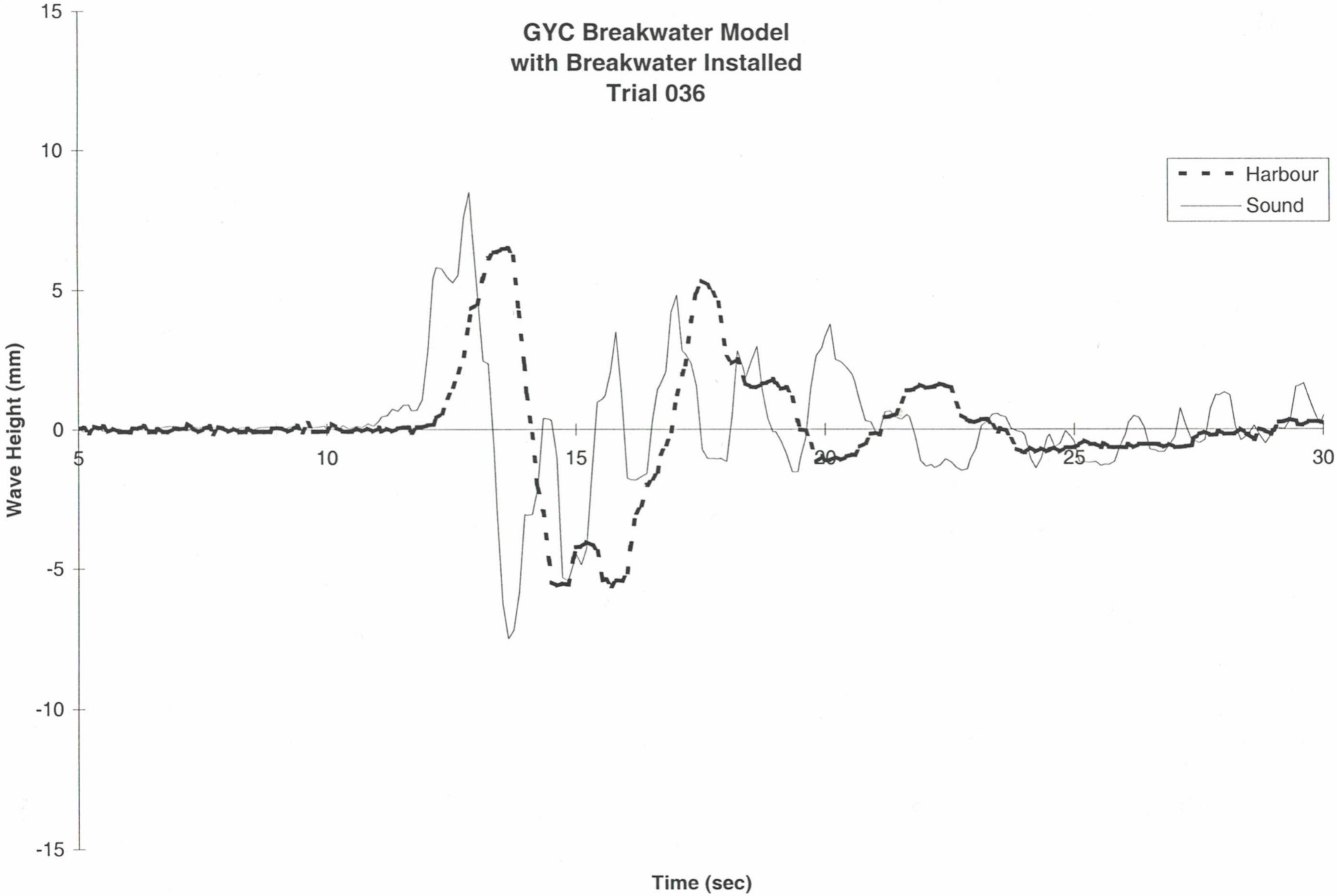


GYC Breakwater Model
with Breakwater Installed
Trial 032
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30


GYC Breakwater Model
with Breakwater Installed
Trial 033
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30


GYC Breakwater Model
with Breakwater Installed
Trial 034
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30


GYC Breakwater Model
with Breakwater Installed
Trial 035
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30


GYC Breakwater Model
with Breakwater Installed
Trial 036
Harbour
Sound
Wave Height (mm)
Time (sec)
15
10
5
0
-5
-10
-15
5
10
15
20
25
30