Vibration Analysis of the Crystal River Unit 3 Reactor Containment Structure

November 17, 2009
Rev. 2

Summary:

The analysis presented here is part of the root cause investigation by Performance Improvement International of the Reactor Building Containment Wall failure during the Steam Generator Replacement (SGR).

This analysis considers the entire Reactor Building and does not include the detail modeling that may predict local stress concentrations. Further, the wall at the SGR opening location is assumed to be intact in this analysis.

The vibration of the Reactor Building due to the following loads are modeled and analyzed:

- Hydro Cutting of the SGR opening
- Shock Load of Cutting Post-Tensioned Wires

The result of this analysis is:

1. The resonant frequencies of the structure are:
   a. 4.43 Hz – Swaying of Reactor Building
   b. 6.42, 7.48 & 8.37 Hz – Vibration frequencies of Wall Panels between buttresses
2. The modal analysis compares favorably to physical testing (7.4 Hz calculated vs. 7.3 Hz measured).
3. The vibration induced by Hydro Cutting for the SGR opening produces displacements less than 3.5×10^{-4} inch and tensile stresses less than 0.55 psi in the concrete.
4. The shock load of cutting 20 individual Wire Strands of one Hoop Tendon at one time induces vibrations with displacements less than 7×10^{-3} inch and tensile stresses less than 11 psi in the concrete.

P/69

Analysis Objective

The objective of the presented analysis is to study the following two loads for vibrations of the Reactor Containment Structure:

1. Pulsating load of the Hydro Cutting
2. Shock load of cutting of 20 individual Wire Strands of one Hoop Tendon at one time

Modeling Approach and Properties

The geometry of the Crystal River Plant Unit No. 3 Containment structure was modeled based on references 1 though 10. Abaqus version 6.9-1 Finite Element Analysis software was used to model and analyze the structure.

The following components of the structure are included in the model:

1. Concrete base (cylindrical geometry)
2. Concrete wall panels and buttresses (6 panels and 6 buttresses)
3. Concrete dome
4. Interior steel liner (3/8 inch thick wall and roof, 1/4 inch floor)
5. 144 Vertical Tendons (24 ea × 6 Bays) equally spaced around 360 degrees
6. 282 Hoop Tendons (47 ea × 6 Pairs of Bays)

The concrete structure is modeled using the 8-node linear brick elements with incompatible modes, C3D8I, for accurate bending representation. The steel liner is modeled using the 4-node linear shell element S4. The vertical and horizontal tendons are modeled using the 2-node truss element T2D2. The truss elements are embedded in the solid concrete elements with a prescribed initial stress.

The Tendons are made up of 163 individual wire strands, each with a diameter of 7 mm). The Tendons are modeled as being tensioned to 1,400 kip force which results in a prescribed stress of roughly 144,000 lb/in^2.

The Modulus of Elasticity and Mass Density of the concrete is based on Reference 11. The Poisson's Ratio of the concrete is based on Reference 12:

- $E_C = 4.287 \times 10^6\ lb/in^2$
- $\nu_C = 0.2$
- $\rho_C = 150\ lb/ft^3$

The steel Tendon and Liner properties are taken as:

- $E_S = 30 \times 10^6\ lb/in^2$
- $\nu_S = 0.29$
- $\rho_S = 0.282\ lbm/in^3$

The bottom of the concrete base is fixed in all translational degrees of freedom.

Finite Element Model Description

The model consists of three types of Finite Elements:

1. Continuum Solid Elements (C3D8I) representing the concrete structure
2. Structural Shell Elements (S4) representing the steel Liner Interior
3. Structural Truss Elements (T2D2) for the representation of the Vertical and Hoop Tendons

Figure 1 depicts the mesh of the concrete structure and the steel liner.

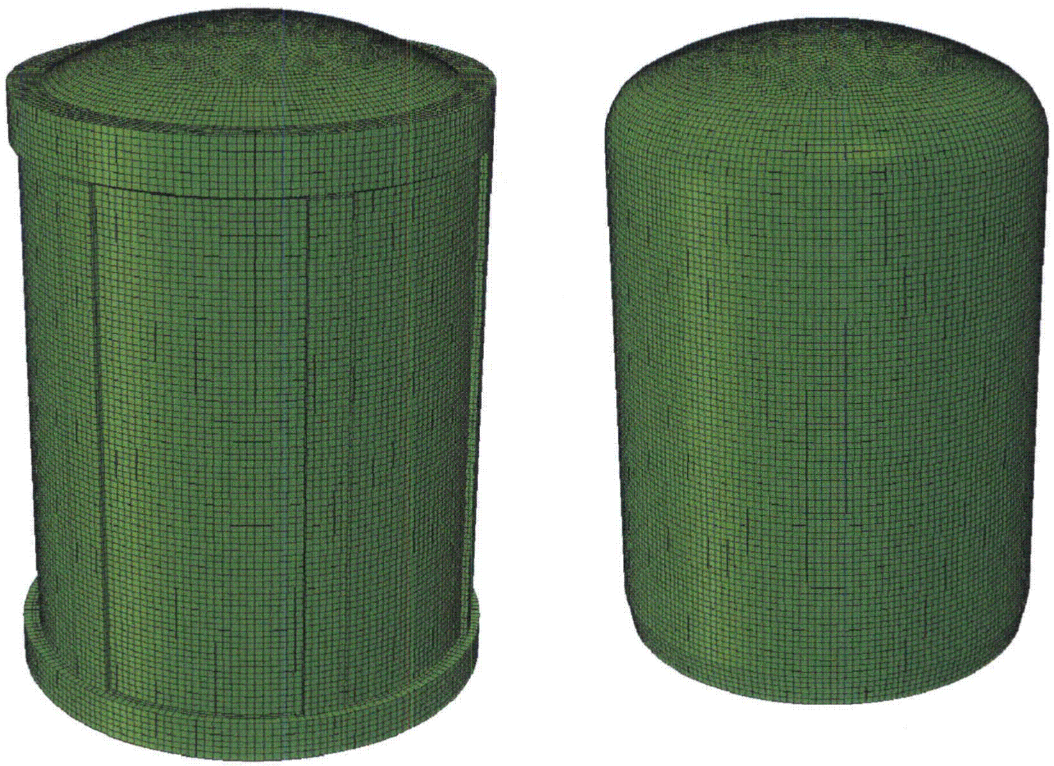


Figure 1: Finite Element Mesh of the Reactor Building. The exterior shown on left and the interior liner mesh shown on the right.

Figure 2 shows the mesh of the Vertical and Hoop Tendons and the location on the solid structure.

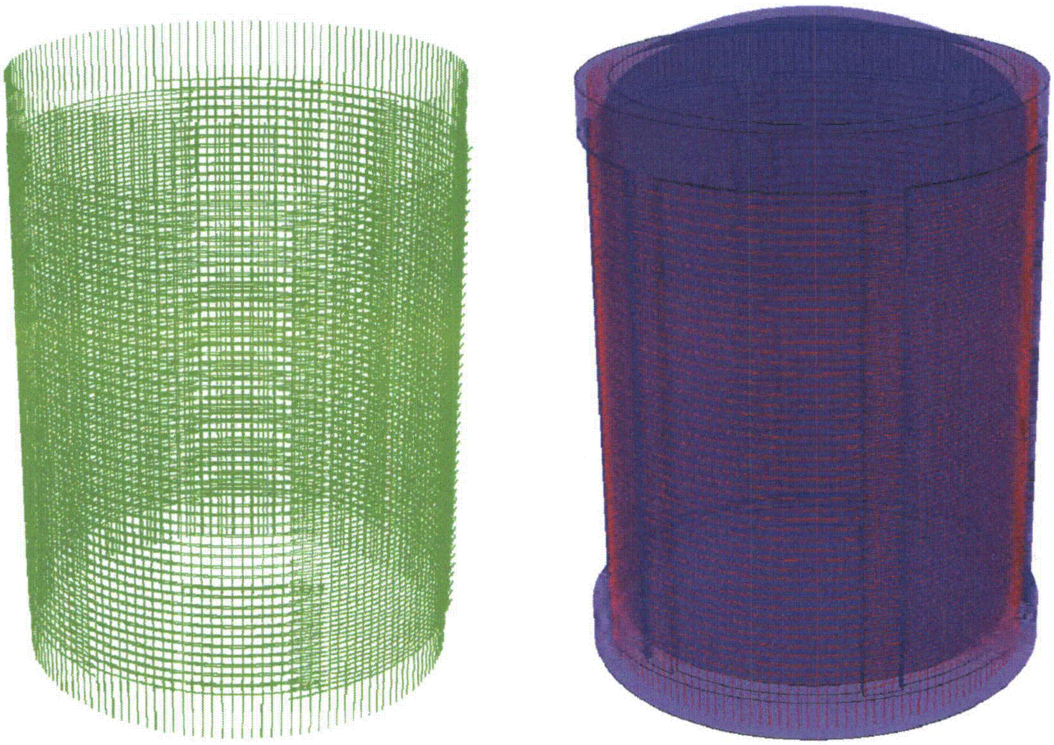


Figure 2: Vertical and Hoop Tendons shown separately on the left and where they are embedded in the concrete solid structure on the right.

Frequency Analysis

The frequency analysis is performed after a static baseline analysis which includes the tensioning of the Tendons and the application of gravity acceleration.

The following vibration modes and associated natural frequencies are found:

- Mode 1 & 2 (4.43 Hz): Swaying of the structure (increasing vibration amplitude with height)
- Mode 3 (6.42 Hz): Radial vibration of the panels of the cylindrical structure. The mode is three panels deflecting in as the other three are deflecting out (every other in and every other out)
- Mode 4 (6.57 Hz): Radial vibration of the cylindrical structure - similar to Mode 3 but rotated 30 degrees such that the buttresses are mostly vibrating instead of the panels
- Mode 5 & 6 (7.48 Hz): Radial vibration of the cylindrical structure with two peaks and two valleys in the circumferential direction
- Mode 7 & 8 (8.37 Hz): Radial vibration of the cylindrical structure with four peaks and four valleys in the circumferential direction
- Mode 9 (8.88 Hz): Twisting of the structure around the vertical centerline.
- Mode 10 & 11 (12.1 Hz): vibration of the cylindrical structure with five peaks and five valleys in the circumferential direction.

Experimental Validation of Frequency Analysis

The natural frequencies of the Containment Structure were measured by Crystal River Unit 3 Personnel (Reference 13). Accelerometers and two types of excitations were employed: (1) hammer impact, and (2) movement of the Polar Crane and lifting equipment during the installation of the Replacement Steam Generator.

The hammer test mostly excites the following frequencies: 7.3 Hz and 15 Hz where the 15 Hz is likely the first harmonic of the 7.3 Hz vibration. However, careful inspection of the spectrum plot of the wall between Buttress 2 and 3 (in Ref. 13) indicates a small peak around 4 Hz. Typically, hammer impact tests may excite more high frequencies than low frequencies. It is likely that the hammer impact test is not exciting the very low frequency associated with the swaying of the structure. In order to excite the tower swaying modes (Mode 1 & 2) a higher amount of energy that a hammer can produce may be needed.

The inspection of the spectrum that was collected during the movement of the crane clearly shows a peak at around 4 Hz. The movement of the crane will likely produce much higher energies and able to excite the bending vibration modes (Mode 1 & 2).

The frequency analysis of the Finite Element Model indicates that the following set of vibration modes exists of the radial vibration of the wall panels (between buttresses):

- Mode 3 (6.42 Hz)
- Mode 5 & 6 (7.48 Hz)
- Mode 7 & 8 (8.37 Hz)
- Mode 10 & 11 (12.1 Hz)

The three closely spaced natural frequencies of the model (6.42, 7.48 and 8.37 Hz) produce the average frequency 7.4 Hz. Depending on what the resolution of the test instrument is and the amount of averaging used, it is likely that the test was unable to resolve the closely spaced frequencies in this range.

It is concluded that the FEA model is likely a good approximation of reality (7.4 Hz calculated vs. 7.3 Hz measured).

Transient Dynamic Analysis of Hydro Demolition

A Modal Dynamic Analysis including the first 50 modes of free vibration along with the natural frequencies and the associated participation factors is utilized to study the response of the Reactor Building due to Hydro Demolition loads. Modal damping equal to 2% of the critical damping for each mode is assumed.

According to Reference 14, the Hydro Demolition equipment has the following characteristics:

- High pressure water is ejected from two heads, each containing three nozzles
- The water is pumped using individual positive displacement pumps operating at 500 rpm (8.33 Hz or 52.36 rad/s)
- The average pressure of the water is 17,000 – 17,500 psi
- The nozzles are 1/8 inch in diameter (0.012272 in^2 opening area)

For this analysis, it is assumed that the pressure pulsation is 25% of the average pressure. It is conservatively assumed that all nozzles are pumping water in phase. The average pressure was converted to a force as follows:

$F_{average}$ = (3 nozzles) × (2 heads) × (17000 psi pressure) × (0.012272 in^2 nozzle opening area) = 1252 lbf

The equation of the time dependent force used in the model is:

(1252 lbf) × (1 + 0.25 × Sin[52.36 *t*]), where *t* is time in seconds.

The force was conservatively concentrated at the most critical point at the midpoint of the bottom SGR opening.

In addition to the abovementioned Hydro Cutting load, the dynamic response to the following loads are also analyzed:

1. Higher pressure (22,000 psi) at 600 rpm
2. Higher pressure (22,000 psi) at 500 rpm
3. Higher pressure (22,000 psi) at 385 rpm (= 6.42 Hz, resonant frequency of Mode 3)

The third additional load listed above is the worst case hypothetical load where the forcing frequency exactly matches the lowest resonant frequency of the wall panels.

Figure 3 shows the maximum Principal Stress of the concrete structure due to load 17,000 psi @ 500 rpm, and 22,000 psi @ 600 rpm.

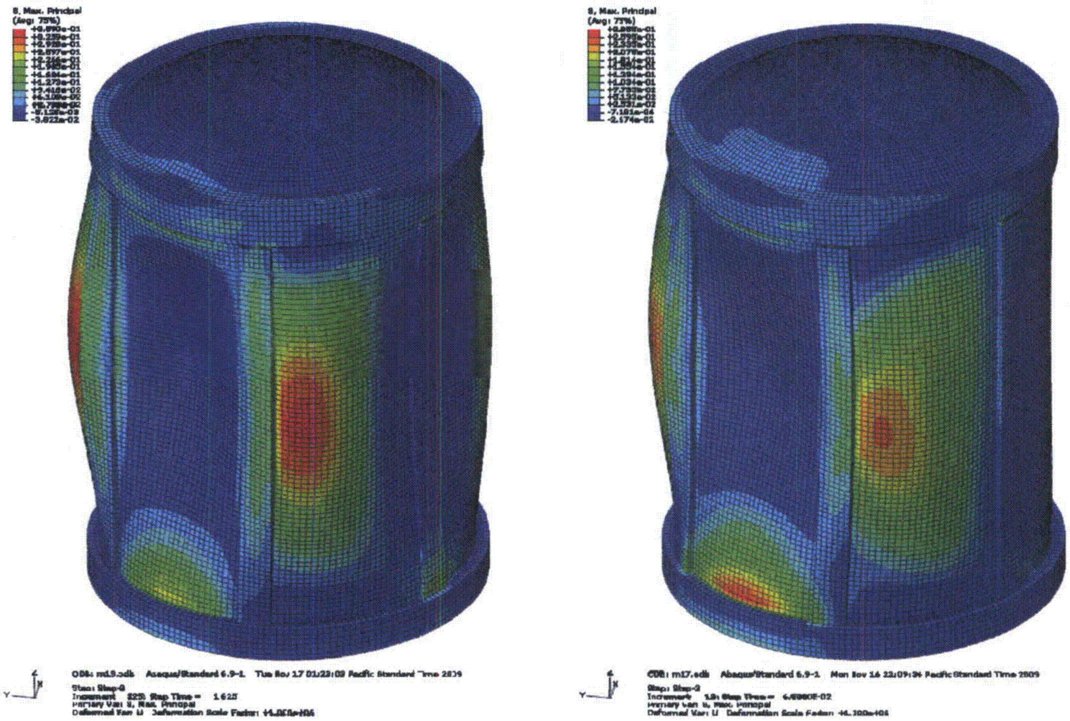


Figure 3: Maximum Principal Stress contours (psi) due to the Hydro Blasting load (17,000 psi @ 500 rpm on the left, and 22,000 psi @ 600 rpm on the right)

Figure 4 shows the maximum displacement of the structure due to the Hydro Blasting loads for the first 2 seconds for loads 17,000 psi @ 500 rpm; 22,000 psi @ 500 rpm; and 22,000 psi @ 600 rpm.

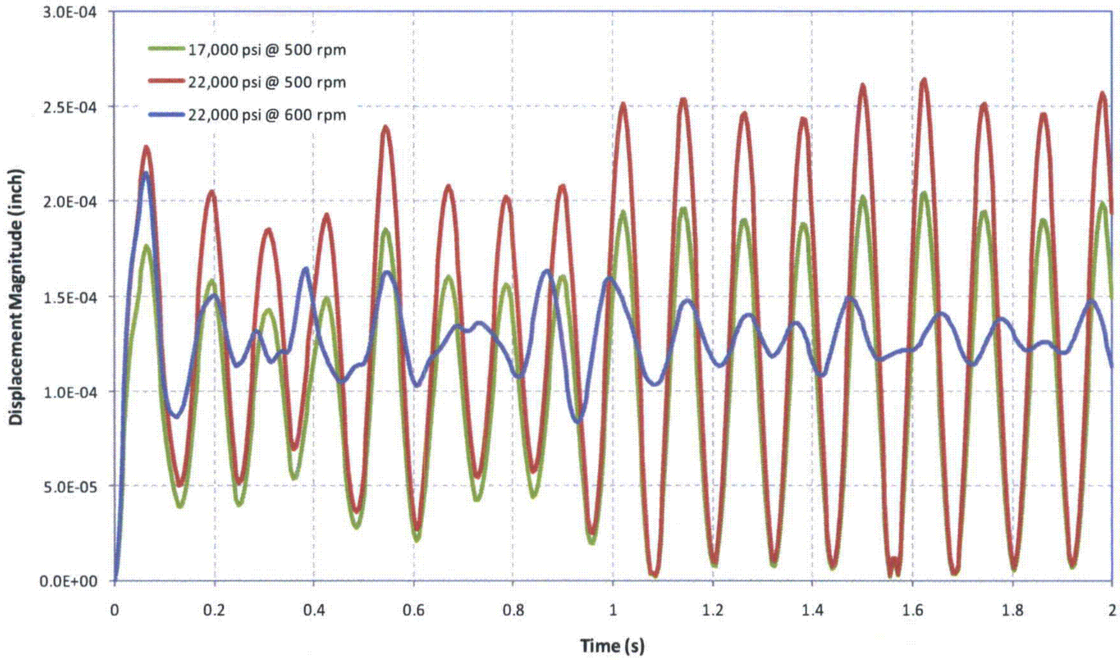


Figure 4: Maximum Displacement Magnitude (inch) of the Reactor Building due to three Hydro Cutting loads for the first two seconds.

Figure 5 shows the dynamic response due to the hypothetical worst case load where the forcing frequency matches the lowest natural frequency of the wall panel. As seen in the figure, the vibration of the wall panel reaches steady state within 4 seconds. After four seconds the amplitude of vibration is not increasing as the damping energy equals the applied energy due to the Hydro Cutting load.

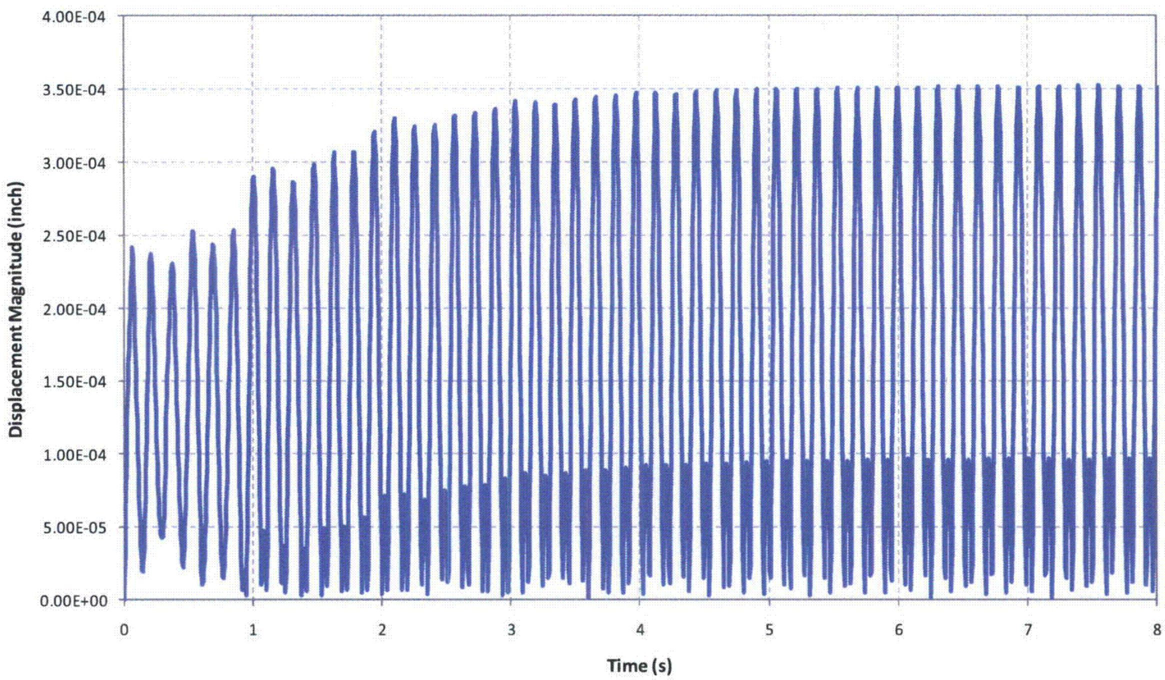


Figure 5: Maximum Displacement Magnitude (inch) of the Reactor Building due to the Hydro Cutting load 22,000 psi @ 385 rpm for the first eight seconds.

The summary of the Maximum Displacement and Maximum Principal Stress due to the Hydro Cutting loads analyzed are listed in Table 1.

Table 1: Displacement and stress results of the concrete structure due to various Hydro Blasting loads.

Hydro Cutting Pressure (psi)	Hydro Cutting Frequency (rpm)	Max Displacement Magnitude (in)	Max Principal Tensile Stress (psi)
17,000	500	2.0×10^{-4}	0.36
22,000	500	2.6×10^{-4}	0.46
22,000	600	2.2×10^{-4}	0.29
22,000	385 (wall resonance)	3.5×10^{-4}	0.55

References

1. Gilbert Associates, Inc., 1970, drawing "Reactor Building Exterior Wall – Concrete Outline"
2. Florida Power, Final Safety Analysis Report, Revision 31.3, Figure 5-2 "Reactor Building Typical Details"
3. Florida Power, Final Safety Analysis Report, Revision 31.3, Figure 5-18 "Base – Cylinder Junction Detail"
4. Florida Power, Final Safety Analysis Report, Revision 31.3, Figure 5-21 "Reactor Building Segments"
5. Florida Power, 1998, drawing "IWE/IWL Inspection Hoop Tendon 13 Layout"
6. Florida Power, 1998, drawing "IWE/IWL Inspection Hoop Tendon 42 Layout"
7. Florida Power, 1998, drawing "IWE/IWL Inspection Hoop Tendon 53 Layout"
8. Florida Power, 1998, drawing "IWE/IWL Inspection Hoop Tendon 64 Layout"
9. Florida Power, 1998, drawing "IWE/IWL Inspection Hoop Tendon 51 Layout"
10. Florida Power, 1998, drawing "IWE/IWL Inspection Hoop Tendon 62 Layout"
11. MPR Associates, Inc., 11/3/2009, "Radial Pressure at Hoop Tendons", Calculation No. 0102-0906-0135
12. Progress Energy, 11/8/1985, "Design Basis Document for the Containment", Rev. 6
13. Memorandum from Virgil W. Gunter, CR3 Systems Engineering, 11/14/2009, "Report of CR3 Containment Structure Vibration Monitoring and Impact Testing"
14. Telephone Interview with Dave McNeill (Mac&Mac, Vancouver), 10/28/2009. Documented in "10 28 interview Dave MacNeil.pdf"

US 20040182960A1

(19) United States
(12) Patent Application Publication (10) Pub. No.: US 2004/0182960 A1
Hach (43) Pub. Date: Sep. 23, 2004

(54) DUAL NOZZLE HYDRO-DEMOLITION SYSTEM

(75) Inventor: William W. Hach, Baltimore, MD (US)

Correspondence Address:
H JAY SPIEGEL
P.O. BOX 444
MOUNT VERNON, VA 22121 (US)

(73) Assignee: Ash Equipment Company, Inc. Doing Business as AMERICAN HYDRO INC.

(21) Appl. No.: 10/378,130

(22) Filed: Mar. 4, 2003

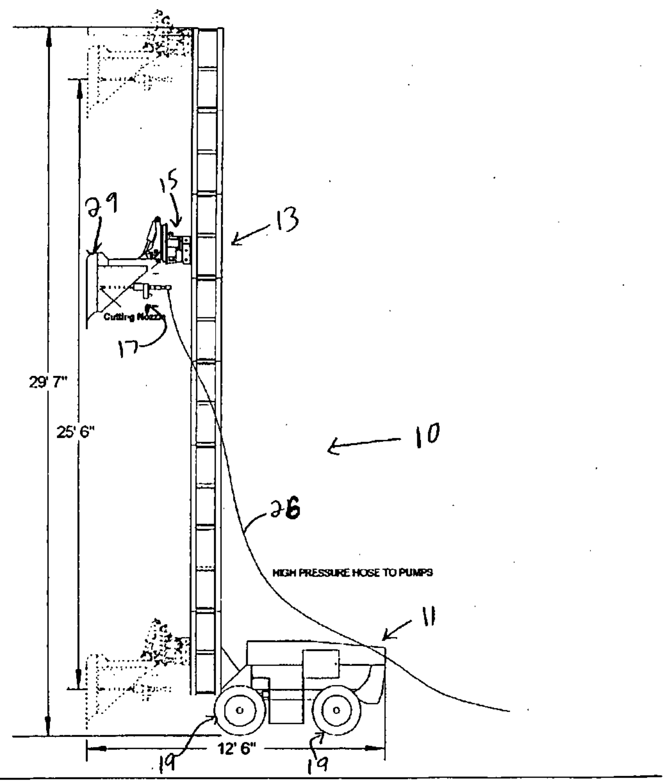
Publication Classification

(51) Int. Cl.[7] B02C 19/18

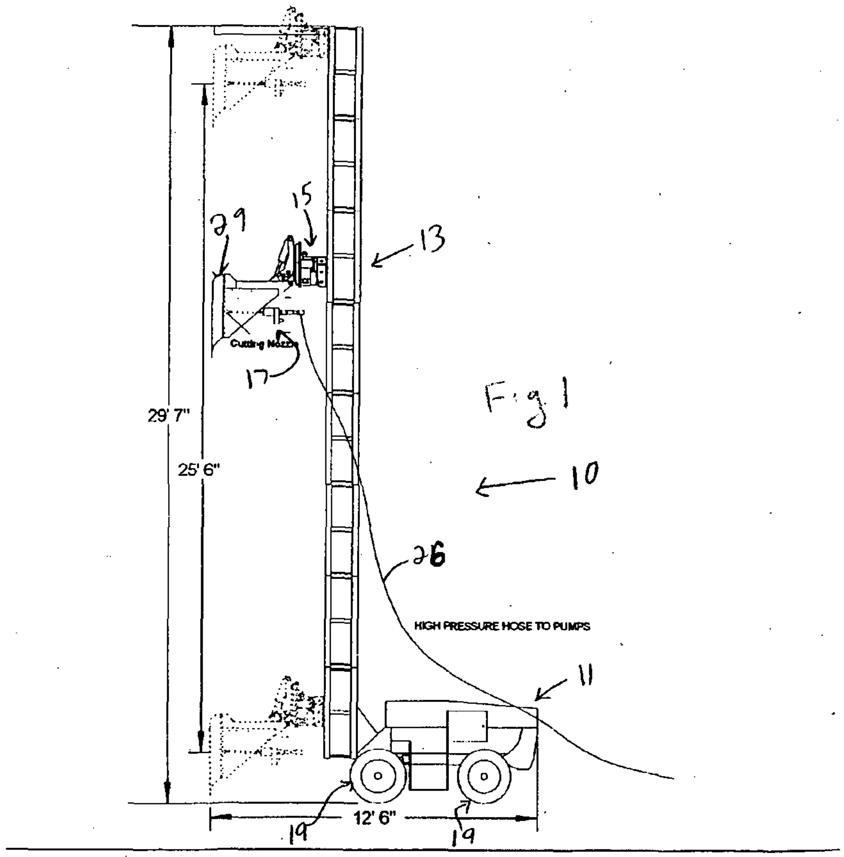
(52) U.S. Cl. 241/301; 241/1

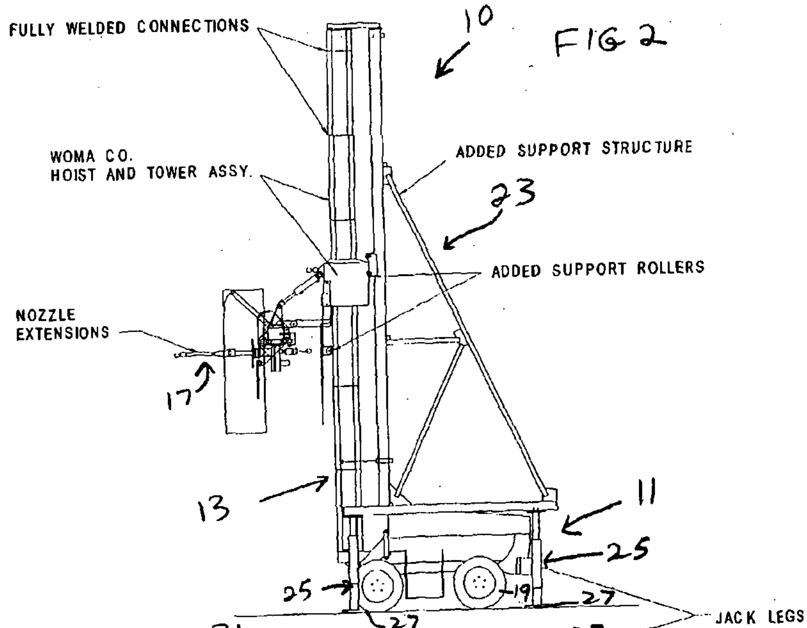
(57) ABSTRACT

A dual nozzle hydro-demolition system is mounted on a robot vehicle having a tower, with the robot vehicle and tower permitting the device to be positioned in any desired location on a vertical wall surface. The robot vehicle includes a plurality of tires and a motive power system allowing it to be moved to a desired location. Bearing pads are mounted on jacks allowing the tires of the robot vehicle to be elevated slightly off the ground to preclude undesired movements. A carriage is slidably mounted on a beam and carries dual nozzles, each of which is connected to a supply of high pressure water via a heavy duty hose. The nozzles are rotated using a hydraulic motor. A coupling is provided within the flow circuit from the source of water to the nozzle allowing a conduit adjacent the nozzle to rotate with respect to a conduit receiving water from the source thereof, so that each nozzle can be rotated without any water leakage.



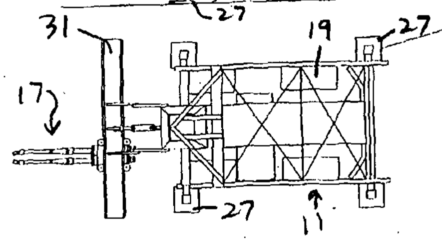
Patent Application Publication Sep. 23, 2004 Sheet 1 of 7 US 2004/0182960 A1





FULLY WELDED CONNECTIONS
10
WOMA CO.
HOIST AND TOWER ASSY.
ADDED SUPPORT STRUCTURE
23
ADDED SUPPORT ROLLERS
NOZZLE
EXTENSIONS
17
13
11
25
25
19
27
27
JACK LEGS

FIG 2



31
19
27
17
27
11

FIG 3

Patent Application Publication Sep. 23, 2004 Sheet 3 of 7 US 2004/0182960 A1

FIG 4

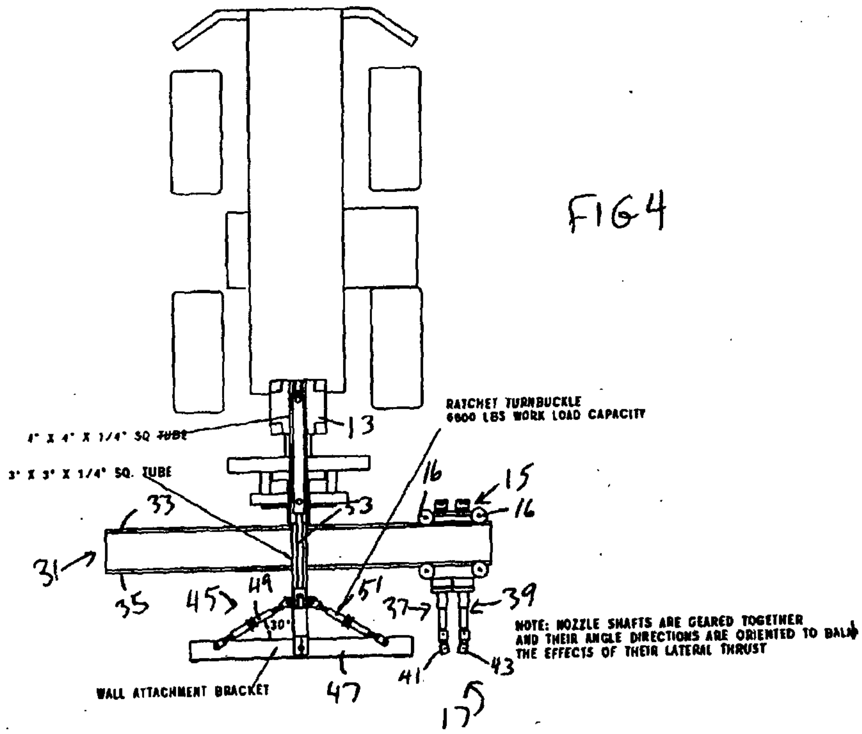
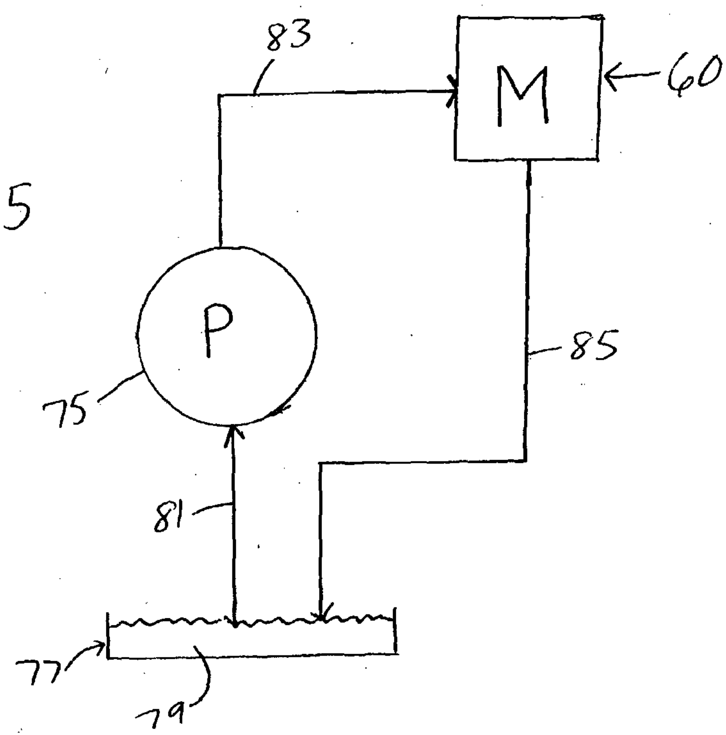


FIG 5



Patent Application Publication Sep. 23, 2004 Sheet 5 of 7 US 2004/0182960 A1

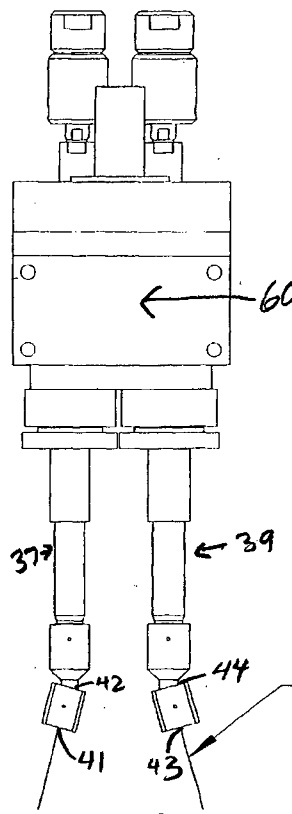


FIG 9

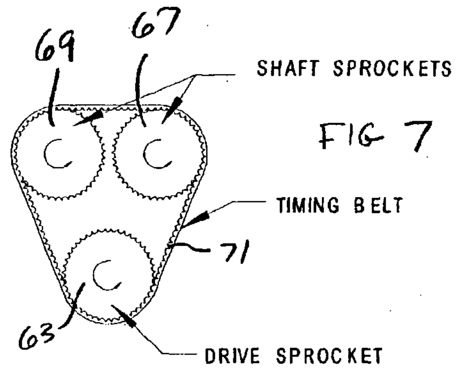


FIG 7

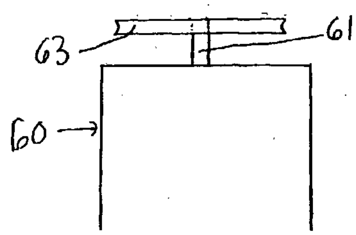
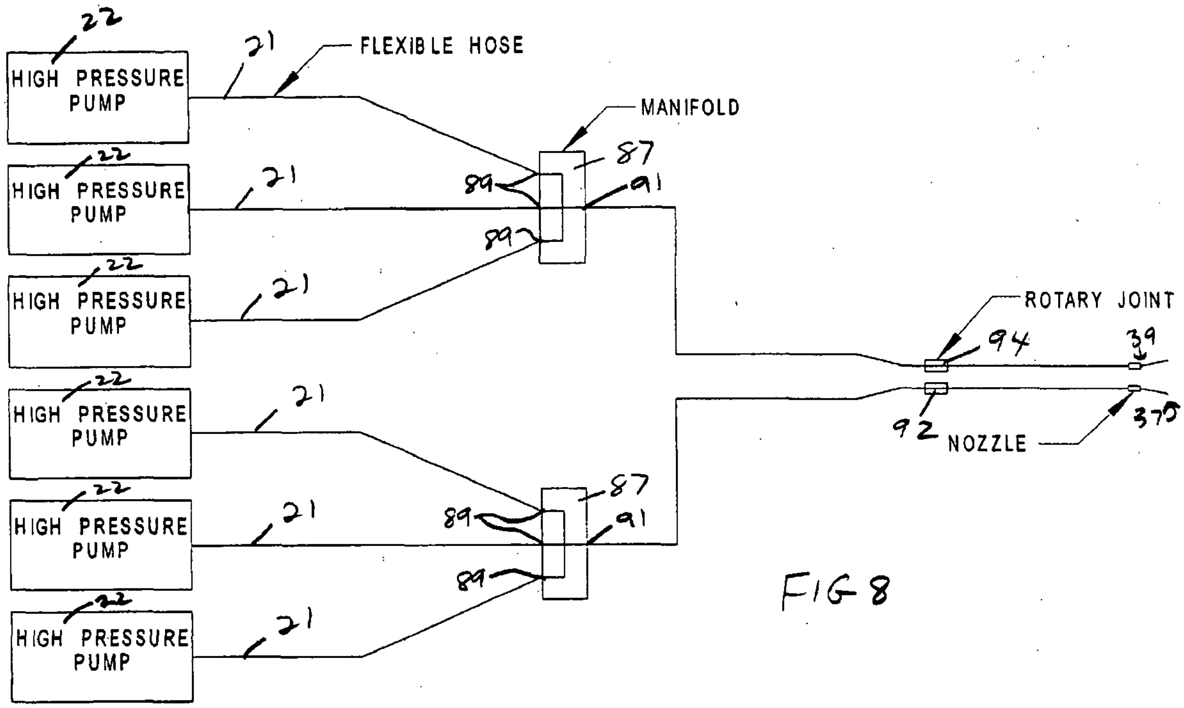


FIG 6

Patent Application Publication Sep. 23, 2004 Sheet 6 of 7 US 2004/0182960 A1



HIGH PRESSURE WATER FLOW DIAGRAM

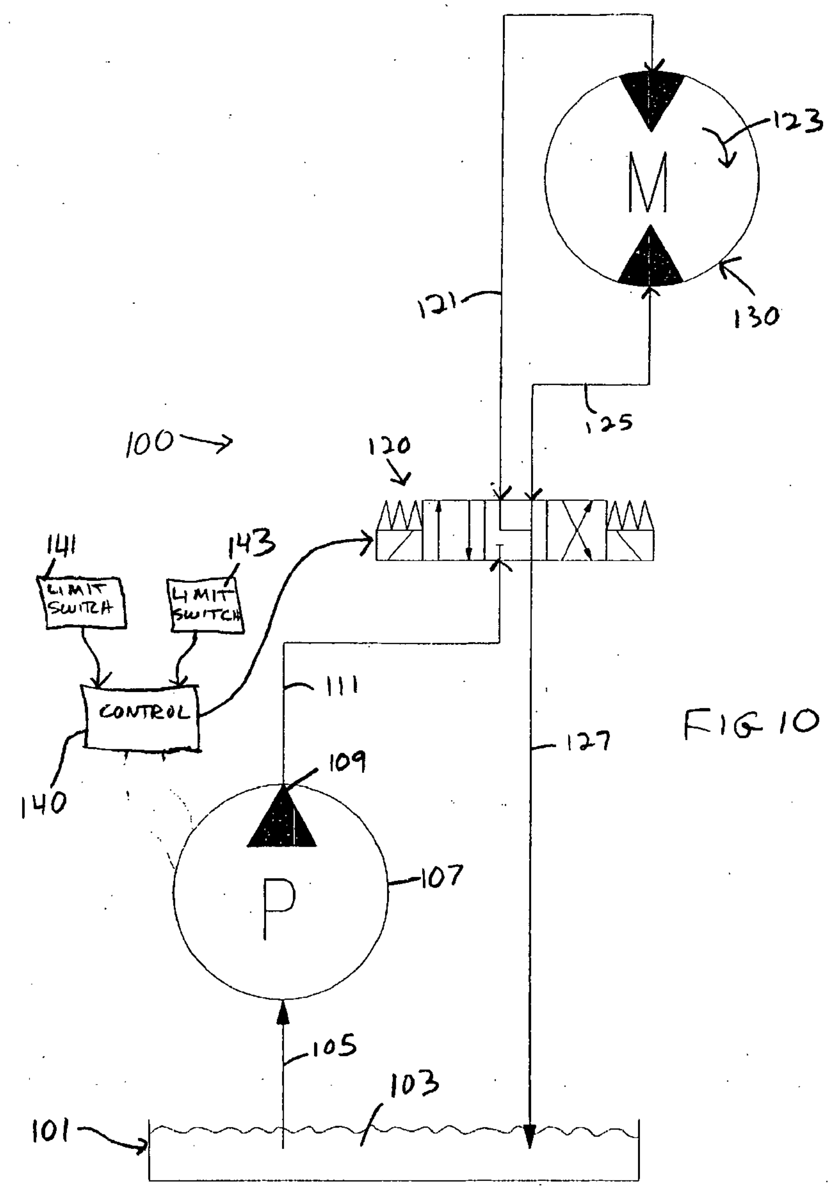

M
123
130
121
125
100
120
141
143
LIMIT SWITCH
LIMIT SWITCH
CONTROL
140
111
127
109
P
107
105
103
101

FIG 10

DUAL NOZZLE HYDRO-DEMOLITION SYSTEM

BACKGROUND OF THE INVENTION

[0001] The present invention relates to a dual nozzle hydro-demolition system. In the prior art, it is known to demolish concrete using a single nozzle system in which a nozzle is reciprocated along a beam while it is also caused to rotate so that high pressure water can be used to pulverize concrete in a wall or floor or road surface. Systems that are known in the prior art are limited in that flow capacity and pressure are limited, thereby limiting the depth of concrete that may be pulverized. Furthermore, such systems are limited in that they are only able to be employed at or near ground level.

[0002] Further, due to limitations on flow through such devices, speed of pulverization is also limited. Thus, for example, to pulverize a certain thickness of concrete, several passes of the rotating nozzle back and forth are necessary. If the capacity for water flow of the device could be increased, the number of passes back and forth necessary to complete the pulverization would be drastically reduced along with the time period during which such pulverization takes place.

[0003] It is with these needs in mind that the present invention was developed.

SUMMARY OF THE INVENTION

[0004] The present invention relates to a dual nozzle hydro-demolition system. The present invention includes the following interrelated objects, aspects and features:

[0005] (1) In a first aspect, the inventive device is mounted on a robot vehicle having a tower, with the robot vehicle and tower permitting the inventive device to be positioned in any desired location on a vertical wall surface. The tower allows reciprocation of a frame carrying the nozzles up to the height limit thereof to facilitate pulverization of concrete at elevations several stories off the ground.

[0006] (2) The robot vehicle includes, in one example, a plurality of tires and a motive power system allowing it to be moved to a desired location. Of course, if desired, the tires can be provided without motorization so that the robot vehicle can be towed and positioned in a desired location and orientation.

[0007] (3) Bearing pads are provided on the robot vehicle, with the bearing pads being mounted on jacks allowing the tires of the robot vehicle to be elevated slightly off the ground to preclude undesired movements thereof. Tie-downs may also be provided to facilitate firm securement of the robot vehicle in a desired fixed location, taking into account the large force generated by high pressure water.

[0008] (4) The heart of the device consists of a carriage slidably mounted on a beam mounted on the frame and reciprocable back and forth along the beam through the use of a sprocket, chain and hydraulic motor drive system. The motor is rotated in one direction or another through the use of a unidirectional pump that is electrically activated and the direction of rotation of the motor is reversible through operation of a reversing valve. Switches mounted on the beam are tripped when the carriage reciprocates to them, with the switches causing the tripping of an electrical circuit which moves the valve to a position causing the direction of rotation of the motor to reverse, to thereby reverse the direction of movement of the carriage along the beam. The position of the switches may suitably be adjusted to adjust the extent of travel of the carriage on the beam.

[0009] (5) The carriage carries dual nozzles, each of which is connected to a supply of high pressure water via a heavy duty hose. In one embodiment of the present invention, each nozzle receives water via a manifold having a single outlet and plural inlets, with each outlet supplying a nozzle. Each inlet is connected to a high pressure pump fluidly connected to a water source. If only one nozzle is being used, water flow to the other nozzle may be shut off by shutting of the high pressure pumps associated therewith.

[0010] (6) Preferably, the nozzles are rotated using a hydraulic motor. In one embodiment, the hydraulic motor rotates a drive sprocket coupled to a driven sprocket on each drive shaft for each particular nozzle via a common flexible drive belt or timing belt. A coupling is provided within the flow circuit from the source of water to the nozzle allowing a conduit adjacent the nozzle to rotate with respect to a conduit receiving water from the source thereof, so that each nozzle can be rotated without any water leakage.

[0011] As such, it is a first object of the present invention to provide a dual nozzle hydro-demolition system.

[0012] It is a further object of the present invention to provide such a system in which a mobile robot is used to position the device for pulverization of concrete.

[0013] It is a still further object of the present invention to provide such a device in which an elevated boom is affixed to the mobile robot to allow elevation of the nozzles to a desired elevation for pulverization of concrete off the ground.

[0014] It is a yet further object of the present invention to provide such a system in which a plurality of nozzles are supplied with high pressure water and are rotated at a desired rate of rotation.

[0015] It is a yet further object of the present invention to provide such a device in which a shroud protects the operator from the high pressure water and debris formed during demolition.

[0016] It is a still further object of the present invention to provide such a device with a wall attachment bracket allowing attachment to a wall surface that is being demolished.

[0017] These and other objects, aspects and features of the present invention will be better understood from the following detailed description of the preferred embodiment when read in conjunction with the appended drawing figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] **FIG. 1** shows a side elevation view of the preferred embodiment of the present invention.

[0019] **FIG. 2** shows a further side elevation view showing additional details not shown in **FIG. 1**.

[0020] **FIG. 3** shows a top view of the device illustrated in **FIG. 2**.

[0021] **FIG. 4** shows an enlarged top view showing details of the carriage, beam, and wall attachment bracket of the present invention.

[0022] FIG. 5 shows a schematic representation of a preferred hydraulic circuit for rotating the nozzles.

[0023] FIG. 6 shows a top view of a drive motor and pulleys for rotating the nozzles of the present invention.

[0024] FIG. 7 shows a front view of the relationship of pulleys and belts between the motor and nozzles.

[0025] FIG. 8 shows a schematic representation of the water circuit for the nozzles of the present invention.

[0026] FIG. 9 shows an enlarged top view of the nozzles and drive system therefor.

[0027] FIG. 10 shows a schematic representation of the hydraulic drive system for the carriage.

SPECIFIC DESCRIPTION OF THE PREFERRED EMBODIMENT

[0028] Reference is first made to FIGS. 1-4 so that an overview of the structure of the present invention will be best understood.

[0029] With reference to FIG. 1, the present invention is generally designated by the reference numeral 10 and is seen to include a robot vehicle 11, a boom 13, a carriage 15, and cutting nozzle assembly 17 (shown in a stored position). The robot vehicle 11 includes a plurality of tires 19 allowing the vehicle 11 to be moved to any desired location. The carriage 15 is mounted to the boom 13 using a frame in a manner not shown in detail but permitting the carriage 15 to be reciprocated to any desired vertical position along the boom 13. A second alternative position for the carriage 15 is seen in phantom at the top of FIG. 1.

[0030] If desired, the robot vehicle 11 may be motorized or, if desired, may just be provided with structure allowing it to be towed and pushed to a desired location. High pressure hoses, such as the hose 26, supply water to the cutting nozzle assembly 17.

[0031] A shroud 29 extends in front of the nozzle assembly 17 to protect the operator from the water and debris mixture created through operation of the present invention. Slots (not shown) in the shroud 29 allow the nozzles to protrude slightly therethrough so that high pressure water can impinge on the wall that is being demolished without interference from the shroud 29.

[0032] With reference to FIG. 2, a bracing structure 23,may be provided interposed between the boom 13 and the robot vehicle 11 permitting bracing of the boom 13 which is necessary given the physical weight of the carriage 15 and cutting nozzle assembly 17 along with the weight of the water conveyed thereto. In FIG. 2, the nozzle assembly 17 is shown extended in the operating position.

[0033] The robot vehicle 11 may also include a plurality of jacks 25, each having a ground engaging pad 27, as best seen in FIG. 3, to permit the robot vehicle 11, tires 19, to be lifted off the ground to preclude movements of the robot vehicle 11 during pulverization operations.

[0034] With reference to FIG. 4, the carriage 15 is seen to ride on an elongated beam 31 having upper and lower vertical surfaces 33 and 35, respectively, on which ride the wheels 16 of the carriage. The nozzle assembly 17 consist of individual nozzle members 37 and 39 having respective outlets 41 and 43 shown aiming toward one another. The angular relationship between each nozzle termination 41 and 43 and the carriage 15 may be adjusted in a manner well known to those skilled in the art by virtue of ball and socket couplings 42 and 44 (see FIG. 9).

[0035] With further reference to FIG. 4, it is seen that a wall attachment bracket 45 may be provided, including the bracket 47 attachable to a wall using any desired means, and braces 49 and 51 that may include turnbuckles allowing tightening of the braces with respect to a tube 53 that connects the bracket 45 to the boom 13.

[0036] With reference, now, to FIGS. 5-10, certain aspects of the operation of the present invention will now be explained.

[0037] FIG. 6 shows a schematic representation of a hydraulic motor 60 used to drive rotation of the nozzles 37 and 39. The hydraulic motor 60 includes a drive shaft 61 that carries drive sprocket 63. In FIG. 7, the drive sprocket 63 is shown and driven sprockets 67 and 69 are also shown, with the sprocket 67 being coupled to the nozzle 37 and with the sprocket 69 coupled to the nozzle 39. A timing belt 71 couples the sprockets 67 and 69 to the sprocket 63. As should be understood from FIGS. 6 and 7, when the drive shaft 61 rotates, the sprocket 63 rotates therewith, thereby simultaneously rotating the sprockets 67 and 69 along with the nozzles 37 and 39.

[0038] With reference to FIG. 5, the operation of the hydraulic motor 60 which rotates the motor 60 should be understood. The pump 75 is unidirectional and is electrically operated. The sump 77 contains a supply of hydraulic fluid 79. In the direction of rotation of the pump, the conduit 81 conveys hydraulic fluid 79 to the pump 75, to the conduit 83, through the motor 60 to rotate the motor, and thence via the conduit 85 back to the sump 77, thereby rotating the motor, the shaft 61, the sprocket 63, the sprockets 67 and 69 through interaction with the belt 71 and, finally, the nozzles 37 and 39.

[0039] With reference to FIG. 8, the conduits 21 supply water from high pressure pumps 22 to manifolds 87 having three inlets 89 and one outlet 91. Each outlet 91 couples to one of the nozzles 37 or 39 via swivel couplings 92 and 94 that permit rotation of the nozzles 37 and 39 with respect to the manifold 87 while precluding leakage of water therefrom. The user may, shut off one of the nozzles by shutting off its supply pumps 22 and operate the other nozzle by supplying water to it.

[0040] In the preferred embodiment of the present invention, water may be provided at a rate of in the range of 27 gallons per minute at a pressure of in the range of 20,000 psi. The nozzles 37 and 39 may be rotated at a rotative speed at between 75 and 300 rpms.

[0041] In the operation of the present invention, the robot vehicle is conveyed to a desired location and, if desired, the wall attachment bracket 47 may be used to support the top of the boom 13 at a desired location on a wall surface. The conduit 21 is connected to a source of water supply and the belt 71 is coupled between the pulleys as seen in FIGS. 6 and 7. The pump 75 is activated to facilitate rotation of the nozzles 37 and 39 and water flow is activated so that the nozzle ends 41 and 43 spray high pressure water on the wall surface (not shown) that is to be pulverized. Applicant has found that the use of two nozzles greatly enhances the efficiency of the present invention as compared to relatively inefficient prior art systems. In particular, when a single nozzle is employed, Applicant has found that the nozzle must be conveyed back and forth across a wall a number of times to pulverize it. The number of passes necessary to pulverize a wall is greatly reduced when two nozzles, side-by-side, are employed. The dual nozzles cause a greater volume of water to impinge on each region of the wall during any given period of time, thereby speeding up pulverization.

[0042] With the robot vehicle **11** appropriately located and the boom **13** appropriately positioned, the carriage **15** is raised on the boom **13** to a desired elevation and, as explained above, the pump **75** is activated and water pressure is supplied to the nozzles **37** and **39**. The carriage **15** is reciprocated back and forth along the beam **31** back and forth until the region that is being treated has been pulverized.

[0043] With reference to **FIG. 10**, a hydraulic circuit **100** is provided to reciprocate the carriage **15** back and forth. The circuit **100** includes a sump **101** filled with hydraulic fluid **103**. A conduit **105** connects between the fluid **103** and the pump **107**. The pump is activated in any known manner and is unidirectional. The outlet **109** of the pump **107** supplies hydraulic fluid under pressure to the conduit **111** which supplies four port reversing valve **120**. A motor **130** receives hydraulic fluid from the four port reversing valve **120**. In one position of the valve **120**, hydraulic fluid travels toward the motor through the conduit **121** rotating the motor in the direction of the arrow **123** with hydraulic fluid exiting the motor **130** via the conduit **125**, with the fluid traveling through the valve **120**, into the conduit **127** and thence back to the sump **101**. When the valve **120** is moved to its second position, hydraulic fluid in the conduit **111** is supplied to the conduit **125** through the valve **120**, travels through the motor **130** to rotate the motor in a direction opposite to the direction indicated by the arrow **123**, exits the motor **130** via the conduit **121**, travels through the valve **120** to the conduit **127** and thence back to the sump **101**. With this structure, the useful life of the pump **107** is considerably enhanced because the pump is only caused to move in a single direction and its operation is continuous rather than intermittent.

[0044] With further reference to **FIG. 10**, a control **140** causes the switching of the valve **120** back and forth. Limit switches **141** and **143** are mounted on opposite ends of the beam **15**. The positions of the limit switches **141** and **143** may be suitably adjusted along the length of the beam **31** in a manner well known to those skilled in the art. Thus, when the carriage **15** travels along the beam **31** eventually it will engage one of the limit switches which will close, sending a signal to the control **140** which causes the valve **120** to move to its alternate position, thereby reversing the direction of rotation of the motor **130** and accordingly reversing the direction of movement of the carriage **15**. When the carriage **15** travels to the other end of the beam **31** and strikes the other limit switch, a signal is provided to the control **140** which again moves the valve **120** to its first-mentioned position, thereby, again, reversing the direction of movement of the motor **130** and the carriage **15**.

[0045] Thereafter, the carriage **15** is raised or lowered with respect to the boom **13** and the operation is repeated until a swath of wall to the height of the boom **13** and to the width of the beam **31** or any desired lesser width has been pulverized. At that point, the bracket **45** is released and the robot vehicle **11** is moved to a new location where the process is repeated.

[0046] In this way, in a highly efficient fashion, an eptire wall may quickly be pulverized so that a construction process may be continued at the location of the pulverized wall.

[0047] As such, an invention has been disclosed in terms of a preferred embodiment thereof, which fulfills each and every one of the objects of the invention as set forth hereinabove, and provides a new and useful dual nozzle hydro demolition system of great novelty and utility.

[0048] Of course, various changes, modifications and alterations in the teachings of the present invention may be contemplated by those skilled in the art without departing from the intended spirit and scope thereof.

[0049] As such, it is intended that the present invention only be limited by the terms of the appended claims.

1. A hydro-demolition system comprising:

a) a carriage reciprocably mounted on a beam;

b) a pair of fluid nozzles mounted on said carriage, said nozzles being connected to a source of pressurized fluid;

c) means for rotating each nozzle with respect to said carriage; and

d) means for adjusting elevation of said carriage with respect to a ground surface.

2. The system of claim 1, wherein said carriage is carried on a vertically extending boom.

3. The system of claim 2, wherein said adjusting means adjusts elevation of said carriage along said boom.

4. The system of claim 1, wherein each of said nozzles includes an elongated conduit having a swivel whereby said nozzles may rotate with respect to said carriage.

5. The system of claim 1, further including a conduit connected between said source of pressurized fluid and said nozzles.

6. The system of claim 5, wherein just upstream of said nozzles, a manifold is provided for each nozzle including a single outlet coupled to a said conduit and a plurality of inlets, each nozzle coupled to one of said outlets and each inlet coupled to a pressurized supply of water.

7. The system of claim 2, wherein said boom is mounted on a robot vehicle.

8. The system of claim 7, wherein said robot vehicle has a plurality of pads mounted on respective jacks.

9. The system of claim 8, wherein said robot vehicle has four tires, said jacks, when activated, lifting said tires off a ground surface.

10. The system of claim 2, wherein said boom includes a bracket for attaching an upper region of said boom to an adjacent wall surface.

11. The system of claim 4, wherein each nozzle includes an outlet tip at the end of each elongated conduit, each elongated conduit having an axis of elongation, each outlet tip being angled with respect to its respective elongated conduit.

12. A hydro-demolition system comprising:

a) a robot vehicle with a vertically extending boom;

b) a horizontal beam carried on said boom and vertically adjustable along said boom;

c) a carriage mounted on said beam and movable along said beam from one end to another end thereof;

d) a pair of fluid nozzles mounted on said carriage, said nozzles being connected to a source of pressurized fluid; and

e) means for rotating each nozzle with respect to said carriage.

13. The system of claim 12, wherein each of said nozzles includes an elongated conduit having a swivel whereby said nozzles may rotate with respect to said carriage.

14. The system of claim 12, further including a conduit connected between a said source of pressurized fluid and each of said nozzles.

15. The system of claim 14, wherein just upstream of said nozzles, a manifold is provided for each nozzle including a single outlet coupled to a nozzle and a plurality of inlets, each inlet coupled to a said source of pressurized fluid.

16. The system of claim 12, wherein said robot vehicle has a plurality of pads mounted on respective jacks.

17. The system of claim 16, wherein said robot vehicle has four tires, said jacks, when activated, lifting said tires off a ground surface.

18. The system of claim 12, wherein said boom includes a bracket for attaching an upper region of said boom to an adjacent wall surface.

* * * * *