OPTIMIZED DESIGN AND PREDICTED PERFORMANCE OF A DEEP OCEAN 50 m PISTON CORING SYSTEM*

C. H. Karnes, S. N. Burchett, and P. T. Dzwilewski[†]

Sandia National Laboratories[‡]
 P. O. Box 5800
 Albuquerque, New Mexico 87185

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ABSTRACT

Calculational techniques are described which were developed or adapted for the purpose of analyzing the mechanical response of a proposed piston coring system capable of recovering high quality 50 m long cores. The analysis includes the effects of barrel geometry on the mass required to penetrate 50 m of an assumed sediment, the effects of non-vertical entry and pullout on the stresses within the barrel, and the effects of steel cable or parachute piston restraints on the resulting core sample distortion. The results show that a wall thickness of 50 mm in the upper section is necessary to survive an entry of up to 1.5° from vertical or a recovery angle of up to 5°. They also show that a mass of 15,400 kg and a pullout force of 330 kN are required. It is shown that active piston control is necessary to eliminate piston motion during penetration.

1. INTRODUCTION

Ocean scientists and engineers have for several decades utilized piston coring devices for obtaining core samples of ocean sediments.¹ In recent years attempts have been made to obtain longer core samples and a few cores as long as 25 to 30 m have been recovered.² The scientific community has a need for even longer cores in order to (1) extend the paleomagnetic time scale to the Mid-Tertiary and correlate it with radio-metrically dateable ash layers, (2) detail the development of the late Cenozoic biostratigraphies, (3) develop high resolution ichthyolith stratigraphies, and others.³ Also, the investigations being conducted by the Subseabed Disposal Program⁴ require detailed analyses of sediments up to 50 m in depth in order to determine chemical and physical properties and to confirm geologic stability and continuity and to confirm homogeneity of properties and stratigraphy throughout major regions.

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[†]Civil Systems, Inc., 2201 San Pedro, N. E., Albuquerque, New Mexico 87110.

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Discussions were held during a Coring Engineering Workshop at Wood's Hole Oceanographic Institution in November, 1977⁵ in which it was concluded that 50 m cores probably could be obtained by extending existing piston coring technology to a carefully analyzed and designed system and by making full use of electronic instrumentation for monitoring system performance.

Not all previous attempts at obtaining long cores have been successful and several coring systems have either been broken or lost.^{6,7} Even when long cores have been recovered, they frequently showed regions of severe disturbance due to inadvertent piston motion.^{8,9}

When a coring system is operating in deep water, two problems exist because of elasticity of the cable: (1) transient cable motion resulting from triggering the coring system to initiate the free-fall phase results in uncontrollable and unpredictable piston motion during the coring operation^{7,10} and (2) even without transients, the elasticity of a long cable will allow it to stretch and the piston to be dragged downward during the coring operation. Both phenomena result in severely disturbed core samples.

The purpose of this paper is to present the results of a detailed parametric study of the mechanical response of a system that will be capable of recovering high quality sediment core samples 50 m in length at essentially unlimited depth. The parameters and responses considered in this study are: inside and outside barrel diameters, step tapered barrel geometry, required mass, buckling and bending of the barrel, piston motion during penetration, and pullout forces. The results include the predicted performance of a coring system designed with workable, if not optimum, parameters.

Tradeoffs are necessary to obtain the optimum design parameters. For example, there is a need to obtain the largest diameter sample practicable to allow biostratigraphical and geotechnical analysis.³ However, increasing the diameter increases the mass required to penetrate 50 m, increases the force required to hold the piston stationary, and increases the pullout force required to recover the system. On the other hand, a small diameter

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barrel will be easier to buckle or bend during penetration. In order to meet the system objectives, the inside diameters considered in the analysis presented here were limited to between 102 and 178 mm. The maximum shear strength of the sediment considered in this study has a logarithmic strength-depth relationship with a maximum shear strength of 40 kPa at 50 m.

This paper first presents a description of the analysis methods either adapted or developed to analyze the system response; presents the results of the parametric study showing the sensitivity of the system performance to changes in design parameters; and then, presents the predicted performance and response of a system which is a workable, optimum design.

It is intended that the analysis methods employed will be directly applicable to existing coring systems of either piston or gravity type. Detailed hydrodynamic, hydroelastic and cable transient analyses have also been performed, but they are topics of separate documents^{11,12} and will not be presented in this paper.

The development of a 50 m piston coring system (officially named the Long Coring Facility or LCF) is a joint program between Sandia National Laboratories and the University of Rhode Island.

2. ANALYSIS METHODS

The methods used to analyze the response of the coring system and to determine the effects of changing the design parameters were either developed as special purpose computer codes for this application or adapted from general purpose computer codes.

Corer Penetration

The penetration of the corer was analyzed using a computer code based on the balance of mechanical energy. Energy losses during penetration are caused by the sediment cohesion and friction on the inside and outside of the core barrel, the resistance at the nose of the corer, and the hydrodynamic drag (Fig. 1). Similar methods have been used in the past by others to study corer and penetrometer performance.^{7,13-15} However, the unique feature of this computer code is that the piston motion is considered and its effect on penetration depth and core quality can be determined.

This computer code was developed for the LCF project, but it is equally applicable to other coring systems. Some of the parameters that can be studied using this code are the corer mass, the inside and outside diameters of the core barrel, the length of the core barrel, step taper core barrels, the freefall height or the entry velocity, the hydrodynamic drag on the corer, the traction forces on the core barrel due to sediment cohesion and friction, the end bearing, and the piston restraint.

The calculational procedure is as follows. The entry velocity is read from the input or is calculated using a closed form solution given the freefall height, the corer mass and buoyancy factor, the corer frontal area, the corer drag coefficient, the density of seawater, and release velocity. Then for each increment of penetration which is chosen by the user, the forces and, hence, energy losses are calculated. These energy losses are subtracted from the initial kinetic energy and the change in potential energy to determine the new kinetic energy. Once the kinetic energy is known, the new velocity is calculated. Knowing the velocity at the beginning and end of a penetration increment, the time increment can be calculated. This procedure is repeated until the kinetic energy becomes zero. Finding the penetration depth where the kinetic energy is zero is facilitated by a feature in the code which allows the use of a smaller depth increment towards the end of the penetration process. The calculational procedure is straightforward and the only difficult part is in determining the forces contributing to losses. These forces are shown in Fig. 1.

The dominant force that stops penetration is the traction on the inside and outside of the core barrel. This traction is caused by the cohesion and friction of the sediment. Because of the short duration of the penetration process (approximately 3-5s), and the low permeability of the ocean sediments of interest, the undrained cohesion, C_u , and undrained friction angle, ϕ_u , are the important sediment properties. The variation in undrained shear strength with depth obtained from the LL44-GPC3 core⁶ (Fig. 2) was used in this study. This sediment represents the maximum strength of interest for this program and it can be characterized by

$$C_u(Z) = 19540 \ln(1 + 0.1189Z) \quad (1)$$

where C_u = cohesion in Pa and Z = depth in m. The undrained friction angle (ϕ_u) for this sediment was zero.

Not all of the shear strength is mobilized during penetration because of remolding, dynamic effects, sediment-core barrel interaction and possibly other reasons. Therefore, a factor (a fraction of the undrained shear strength) is introduced into the traction force model, which is obtained empirically from existing coring data. From the analysis of the LL44-GPC3 event which had a parachute piston restraint,⁶ a factor of 0.26 matched the obtained core length of 24.4 m. Therefore, for the rest of the analysis presented here a factor of 0.26 is assumed. This assumption should be valid because the LCF corer is being designed for this type of sediment and the anticipated core barrel geometry does not differ radically from that used for the LL44-GPC3.

The end bearing or resistance at the nose of the corer was calculated using the following bearing capacity equation:

$$F_{\text{end}} = (N_c C_u + N_q \sigma'_v) A \quad (2)$$

where $\sigma' = \text{effective stress} = (\rho_s - \rho_{sw})g \cdot Z$;
 $N_c, N_q = \text{bearing capacity factors}$; $A = \text{bearing area}$; $\rho_{sw} = \text{density of seawater}$; $\rho_s = \text{density of sediment}$; and $g = \text{gravitational acceleration}$. The bearing capacity factors vary with friction angle and for the sediment assumed here ($\phi = 0$), $N_q = 1$ and $N_c = 9.17$. This same type of analysis is used for step-tapered core barrels where there is a change in diameter and also for the weight stand if it penetrates the sediment.

The hydrodynamic drag on the corer was calculated using the turbulent drag formula:

$$F_{\text{drag}} = \frac{1}{2} \rho_{sw} C_d A V^2 \quad (3)$$

where $C_d = \text{drag coefficient}$, $A = \text{frontal area}$, and $V = \text{velocity}$. It is assumed that most of the hydrodynamic drag is due to the weight stand. A weight stand having a frontal area of 1.0 m^2 and a drag coefficient of 0.25 was assumed in this analysis.

While the traction forces are the most important, the penetration depth is also affected by the piston motion to some extent. For instance, with a parachute piston restraint, the penetration depth of LL44-GPC3 was calculated to be 30 m while the "undisturbed" core was only 24.4 m long. Also, it was calculated that 55 m of penetration was necessary to obtain a 50 m core in this type sediment using an elastic piston restraint (32 mm diameter steel cable). However, as will be discussed below, the piston motion greatly effects the quality of the core.

Piston Motion and Core Distortion

The purpose of the piston is to prevent the corer from plugging, thereby obtaining a longer core. Plugging occurs when it is easier to punch through the sediment than to core it, i.e., when the integrated traction force on the inside of the core barrel becomes greater than the end bearing force plugging will occur. If the piston is immovable, it applies a force to the top of the core that is just equal to the difference between the inside traction force and the end bearing force (Fig. 1) totally preventing plugging and resulting in the core length and the penetration depth being the same (no core shortening). However, if the piston moves, there will be shear distortion in the sediment below the entrance of the core barrel which is subsequently cored. Burns⁵ reported a series of experiments in which he found that various sequences of layering could be obtained from two layers of sediments depending on the position of the piston during penetration. Also, Kallstenius⁹ reported that soft strata may be squeezed out in piston core samples without being detected and that 20 percent deformation (core shortening) may not be detected.

Because the goal of the ICF is to obtain high quality cores, the piston motion and its effect on the core were included in the computer code. The four piston options are: (1) no piston, (2) stationary piston, (3) a cable restraint (neglecting

transient motion), and (4) a parachute restraint. A fifth option, transient elastic cable motion, is under development.

The analysis takes into account the inertia of the cored sample and computes the displacement of the piston and core sample resulting from the forces shown in Fig. 1. The piston force is made compatible with one of the above piston options and the piston and core sample are allowed to move downward until the piston restraint becomes sufficient to prevent additional motion. The results of the computation include the overall core shortening as well as the distribution of distortion (mechanical strain) along the sample.

The no-piston option simulates an open barrel gravity corer and is achieved by equating the piston force to zero.

Option two, which is the stationary piston, is used to determine penetration if the piston is fixed. This is an idealization which may be applicable to shallow water coring with light corers. At great depths, Kullenberg⁷ concluded that it is impossible to immobilize the piston completely using a cable restraint. Analysis of the response of the ICF cable under operating conditions has confirmed Kullenberg's findings.¹² With this option, the force and power necessary to completely fix the piston are obtained. This type of information is needed for a new concept to immobilize the piston as will be discussed later.

The third option is the cable restraint which neglects transient cable motion and assumes that the piston and the core are moved downward by the same amount as the cable is stretched by the piston force. Including the transient cable motion in the analysis would result in the prediction of a much more highly disturbed core. The coupling of the cable transients due to cable rebound and ship motion with the piston motion is currently being developed. While a cable restraint will not be used alone for the ICF, the coupled analysis has wide applicability to existing coring systems.

The fourth option available in the computer code at this time is the parachute restraint. This type of piston restraint was used on the LL44-GPC3 coring event^a and is a way to decouple both the transient and steady-state cable motion from the piston.

Bending Response During Penetration

One of the postulated failure modes of a long coring device is the lateral bending failure of the corer. If the axis of the corer is perfectly parallel to the gravity field (vertical entry), lateral bending failure may be induced due to the lateral buckling or structural instability of the corer. If the corer enters the sediment non-vertically, the corer is subjected to lateral loads which can induce bending failure. In this study, the goal is to define the geometrical parameters of a 50 m coring system which will survive a coring operation without catastrophic bending

failure. To do this it was necessary to develop a methodology, which included defining the loads and restraints on the corer, verifying the method as much as possible and using the method to determine the stability and lateral response of selected corer geometries.

During a coring operation the loads and boundary conditions on the corer are continually changing as a function of time. Closed form analytical expressions to determine the structural stability limits or lateral response are not available. It is necessary, therefore, to utilize numerical techniques to determine the lateral response of the corer during penetration. In this study, the general purpose finite element computer program, ADINA,¹⁸ was utilized.

To verify the applicability of using ADINA to determine the structural stability limits of a corer, calculations were done for comparison with several analytical results. In one of these calculations, a 50 m long beam column with pinned ends was subjected to a concentrated axial compressive load. From Reference 19, the critical buckling load is calculated to be 8.3 kN. To determine the buckling load utilizing ADINA, the 50 m long beam was idealized as 50 equal elements. Because ADINA is a bending code and does not determine stability conditions, the geometry of the beam-column included an initial lateral perturbation. The perturbation imposed was a half sine function with the maximum displacement corresponding to 2.5% of the average diameter of the pipe. An axial load was applied quasi-statically (no inertia effects) until the lateral displacements were growing apparently without bound. The load at this point was taken as the critical buckling load. In Fig. 3, the calculated maximum lateral displacement of the pipe is plotted as a function of applied load. Also shown is the analytically determined buckling load and the results compare favorably.

The 50 m long core barrel was modeled as 50 equal beam elements with a hollow circular cross-section and the 5 m long weight stand was modeled with 5 equal beam elements, however, the outside diameter of this section was increased to obtain the proper mass to penetrate 50 m. This model was assumed to be released 15 m above the sediment/water interface and allowed to free fall. A simple hydrodynamic drag force given by Eq. 3 was applied to the after-body of the corer. When the corer penetrates into the sediment, the traction forces that tend to stop the corer also tend to bend or buckle it and the sediment provides lateral restraint to the corer. If the corer enters vertically, the lateral restraints reduce the buckling potential of the corer; however, if the corer enters non-vertically, the lateral restraints cause bending moments in the corer. The lateral forces on a unit length of corer were derived from unconfined compression tests on LL44-GPC3 type sediment using a similitude approach. Figure 4 shows the idealized lateral force on the corer per unit length as a function of lateral displacement.²⁰ The traction forces and lateral restraints were applied to the finite element idealization of the corer at appropriate times

by utilizing nonlinear truss elements connected to a moving lateral restraint support. The depth dependence was incorporated into the model by assuming five-10 m thick layers of sediment. For example, the lateral restraint provided by the first 10 m of sediment below the sediment/water interface was assumed to be uniform and equal to the lateral restraint at a depth of 5 m.

This finite element idealization was used to determine the dynamic lateral response of a corer penetrating into seabed sediment. If the angle, θ , between the axis of the corer and vertical is zero, no lateral response will be recorded. This is due to the fact that the model has no initial imperfections. It was, therefore, assumed that the axis of the corer was at an angle of 0.1° to the vertical. Non-vertical entries of $\theta = 1.5^\circ$ and $\theta = 3^\circ$ have also been investigated. Output from the analysis includes the motion (acceleration, velocity, and displacement) of the corer as a function of time and stresses due to the combination of bending and axial loads developed in the corer as a function of time.

Pullout Forces

The force necessary to pull out a coring device from the seabed is the summation of the weight of the corer, the weight of the core, the traction force on the outside of the core barrel, the suction force on the core barrel, and the weight of the cable. For these analyses it is assumed that the corer breaks out instantaneously when the applied force reaches the force necessary for pullout.

The weights of the corer, core, and cable are easily obtainable. Only the traction force on the core barrel and the suction forces at barrel diameter changes and the nose need to be determined. As was done for the penetration, it was assumed that the traction force is equal to the integration of a fraction of the undrained shear strength along the length of the core barrel. The shear strength of LL44-GPC3 was used (Eq. 1) and a factor equal to 0.3 was determined from the analysis of the recorded pullout forces of the LL44-GPC3 corer.⁶ This factor was used for all the analyses presented here and is higher than the penetration factor of 0.26. This is probably caused by the partial consolidation of the remolded sediment around the core barrel with an accompanying increase in strength. Integrating Eq. 1 over the outside surface area of the fully penetrated barrel and using a factor of 0.3 gives:

$$F_{tr} = 5862 \pi D_o \left[\left(L + \frac{1}{0.1189} \right) \times \ln(1 + 0.1189L) - L \right] \quad (4)$$

for a uniform diameter barrel, where F_{tr} = traction in Pa, D_o = diameter in m and L = penetration depth in m.

The end suction force was calculated assuming that this is the reverse of bearing capacity.²¹

Bending Due to Non-Vertical Pullout

If the ship drifts before pullout, the angle the cable makes with the axis of the corer could be significant. Non-vertical pullout forces could cause severe bending stresses in the core barrel. To evaluate the magnitude of the stresses, the computer code, ADINA, was again utilized. The corer was modeled with hollow circular cross-section beam elements as was done in the buckling analysis. It was assumed that the corer was fully penetrated (50 m) with the bottom end rigidly restrained. Non-linear truss elements representing the lateral restraint of the sediment were incorporated into the model. The calculated pullout load was statically applied to the top of the weight stand at an angle between the cable and vertical ranging from $\theta = 2.5^\circ$ to 10.0° . Output from the analysis includes the lateral deflection of the corer and stresses due to the applied pullout load.

3. RESULTS OF PARAMETRIC STUDY

Penetration

Using the previously described penetration analysis method, a parameter study was done to determine the mass required to penetrate 50 m in LL44-GPC3 sediment (Eq. 1) for various core barrel diameters. The first part of the study considered uniform core barrels with inside diameters ranging from 102 to 178 mm, and entry velocities of 0, 15, and 25 m/s. Because of the large masses required by the larger inside diameter corers, the range of diameters was reduced to that of 102 to 127 mm and a refined parametric study was performed. The results of that study are presented in Table 1. Various step-tapered barrel geometries were also considered resulting in a reduction in mass by up to 15 percent.

TABLE 1

Requirements for 50 m Long Corer of Various Barrel Diameters for Entry Velocity of 15 m/s

Inside Diam. mm	Outside Diam. mm	Mass kg	Net Pullout Force kN	Min. Steel Cable Diam. mm
102	127	12,400	285	32
102	152	13,600	330	35
102	188	14,800	375	38
102	203	16,500	425	41
114	140	13,300	310	35
114	165	14,700	360	38
114	191	16,100	400	38
114	216	27,500	450	41
127	152	14,400	340	35
127	188	15,700	385	38
127	203	17,200	435	41
127	229	18,900	485	41

Piston Motion and Core Distortion

Typical results from the core distortion analysis are shown in Fig. 5 for both the cable and parachute piston restraint. The local core shortening for a 38 mm steel cable restraint (neglecting transient motion) increased with depth in the core to a maximum of 10.5 percent strain at 50 m. For this type of analysis, the core shortening is independent of the initial entry velocity.

In contrast, the core shortening using a parachute restraint is dependent on entry velocity. The core distortion here also increases with depth especially in the last stages of penetration when the relative velocity between the piston (and parachute) and the corer is small. The parachute used for this example is the same as used on the LL44-GPC3 event⁶ and is obviously too small for a 50 m coring system. Doubling the area of the parachute ($C_d A = 40 \text{ m}^2$) does reduce the core distortion by about 40 percent but it is still unacceptably large near the bottom of the core.

Results of Buckling/Bending Analysis

The buckling and bending responses of eight separate corer geometries have been determined. The assumed geometries are defined in Table 2. Because of the difficulty of the analysis and the number of possible parameters, all corers were assumed to have an inside diameter of $D_i = 120 \text{ mm}$. In this table, the absolute values of the maximum axial stress in the core barrel during penetration are given. For a slight geometry perturbation, $\theta = 0.1^\circ$, the results indicate that a core with a wall thickness of 13 mm, corer A, will catastrophically fail due to buckling. All other assumed corer geometries will survive a vertical entry with only minimal stresses.

If the corer enters the sediment at an angle of $\theta = 1.5^\circ$, corer B (25 mm wall) will catastrophically fail. The stresses in the remaining corer geometries are significant. The typical yield strength of a mild carbon steel is approximately 200 MPa and the yield strength of 4130, 4140, 4340 alloy steels is approximately 480 MPa. Corers C, STC and STD are marginal based on the calculated stresses compared to available material capabilities.

If the corer enters the sediment at an entry angle of 3° , the results indicate that corer geometries C, STC and STD will catastrophically fail. In corer D, STA and STB (50 mm wall), the magnitude of the calculated stresses are marginal. A 3° entry angle is a very severe environment.

In all of the corers, the severe stresses and catastrophic bending failures occur in a 10-12 m long section of the core barrel directly below the weight stand. The severe stresses are caused by "whipping" of the heavy weight stand. The stresses in the lower 40 m of the core barrel are relatively small. In these calculations, the core barrel was assumed to be a continuous pipe with no joints. Good design practice dictates a substantial margin

TABLE 2

Axial Stresses Due to Non-Vertical Entry

Corer	Wall (mm)		M_B (kg)	M_{WS} (kg)	Axial Stresses (MPa)		
	Section 1	Section 2			$\theta = 0.1^\circ$	$\theta = 1.5^\circ$	$\theta = 3^\circ$
A	13	--	2080	11000	*	*	*
B	25	--	4560	9730	27	*	*
C	38	--	7440	7450	23	226	*
D	50	--	10700	5900	12	107	215

	SECTION 1	SECTION 2					
STA	13	50	6400	7500	32	128	250
STB	25	50	7640	7130	15	131	254
STC	13	38	4760	8860	31	213	*
STD	25	38	6000	8500	25	240	*

*Catastrophic failure

of safety especially considering that joint efficiencies will not be 100%. From these calculations, it can be concluded that to insure survival of the corer, the entry angle must be limited to less than 1.5° or the wall thickness of the upper 10-12 m section of the core barrel be made significantly greater than 50 mm.

Pullout Forces

The net pullout forces (which exclude the cable weight) and the required size of steel cable for a factor of safety of 1.0 are given in Table 1. The factor of safety was determined by adding the pullout force and the weight in water of 6000 m of cable and dividing by the elastic limit of the cable. The required steel cable diameters are quite large. At least 40 percent of the load capacity is used by the weight of the cable alone. Consequently, a steel cable is not feasible for the LCF especially considering the analysis assumptions of perfect couplings and splices, and a factor of safety of 1.0 (i.e., no reserve or fatigue capacity). Using a step tapered core barrel will reduce the net pullout force by a maximum of 20 percent but will reduce the required cable diameter by only 6 mm.

Non-Vertical Pullout

The response of a uniform barrel corer, having an inside diameter of 120 mm and wall thickness of 50

mm, to a non-vertical pullout load has been determined. For this geometry the net pullout load has been calculated to be 425 kN. This pullout load was applied to the weight stand of the corer model at angles of $\theta = 2.5^\circ$, 5.0° , 7.5° , and 10.0° . In Fig. 6 the resulting lateral deflection of the corer is shown. For a pullout angle of $\theta = 10^\circ$, the top of the weight stand deflects 1.14 m. In Fig. 7, the resulting maximum stresses in the core barrel are plotted along the length of the corer. To maintain an adequate margin of safety in a 4130, 4140 or 4340 alloy steel ($\sigma_y = 480$ MPa) core barrel, the pullout angle must be limited to 5° or less or the section modulus in the upper portion of the core barrel will necessarily have to be increased.

4. PERFORMANCE WITH OPTIMUM PARAMETERS

The selection of some of the design parameters within the range being considered is somewhat arbitrary. An inside barrel diameter of 120 mm was selected in order to make room for an optional liner and still recover a core sample having a sufficiently large diameter.

For an inside diameter of 120 mm, the buckling/bending analysis shows that a wall thickness of 13 mm in the bottom 25 m of the barrel will survive. Assuming the entry angle can be limited to 1.5° , the analysis also shows that severe bending stresses occur in the top portion of the barrel

and a wall thickness of 50 mm is required in order to have an adequate safety factor. A reasonable barrel geometry, then, is one having a wall thickness of 13 mm in the bottom 20 m, a 25 mm wall in the central 15 m, and a 50 mm wall in the top 15 m.

For the above barrel geometry, the mass required to penetrate 50 m for a range of freefall distances and the net pullout force required to recover it are in Table 3.

TABLE 3
Mass and Pullout Forces

Freefall Distance m	Entry Velocity m/s	Required Mass kg	Net Pullout Force kN
0	0	15,400	330
25	18	12,900	310

The analysis of the piston motion and resulting core sample distortion shows clearly that conventional passive means of restraining the piston are not adequate and that unacceptably large distortion is allowed by either a cable or a parachute restraint. Currently, active feedback piston control systems are being formulated. Although preliminary concepts appear to be viable, many design details need to be resolved. The results of calculations for an ideal, stationary piston indicate that the peak force required to hold it stationary is 110 kN to obtain a 120 mm diameter, 50 m long core. The peak power is 1.3 MW resulting in a total energy requirement of 2.2 MJ. These power and energy requirements are high but the ambient pressure in deep water is sufficient to be utilized as a source.

If an active feedback piston control system cannot be successfully developed, it is important to realize that deep water piston corers do recover significantly disturbed samples and that this disturbance can be analyzed. Knowing the magnitude of such a disturbance will help prevent misinterpretations of the data obtained from the cores.

5. CONCLUSIONS

Calculational techniques have been developed to analyze the mechanical response of coring devices such as the one being proposed for the Long Coring Facility. However, the techniques are applicable to essentially any existing piston or gravity coring device. The analysis shows that, although it appears to be feasible to design a system for obtaining 120 mm diameter cores 50 m long, one must maintain significant control of the entry and pullout angles because of the high bending stresses which can develop even with a 50 mm wall thickness in the upper 15 m of the core barrel. It is further concluded that active piston control is necessary in order to eliminate the otherwise uncontrolled piston motion and resulting high degree of core disturbance.

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Figure 1. Forces acting on the corer and core during penetration.

Figure 2. LL44-GPC3 undrained shear strength.⁶

Figure 3. Comparison of numerically calculated buckling load to Euler critical buckling load for pinned/pinned column.

Figure 4. Idealized sediment lateral support.

Figure 5. Local core shortening for cable and parachute piston restraints.

Figure 6. Deflection of corer D due to non-vertical pullout load.

Figure 7. Maximum stresses in corer D due to non-vertical pullout load.