NEAR SHORE BATHYMETRIC AND TOPOGRAPHIC SURVEYS IN MARMARA SEA

by

Emine Öner Germen

B.S., Geodesy and Photogrammetry Engineering, İstanbul Technical University, 1994

Submitted to Kandilli Observatory and Earthquake Research Institute

in partial fulfillment of

the requirements for the degree of

Master of Science

Graduate Program in Geodesy

Boğaziçi University

2006

ACKNOWLEDGEMENT

I like to give my special thanks to Assoc. Prof. Dr. Haluk Özener for his guidance, supervision and encouragement throughout my long post graduate study and at last this thesis. I am really grateful to meet such a friendly and helpful instructor.

I thank to Prof. Dr. Onur Gürkan for his guidance and Dr. Ahmet Ünlütepe and Assoc. Prof. Dr. Cem Gazioğlu for their advices and suggestions during thesis study.

I also wish to thank to Dr. Onur Yılmaz, Bülent Turgut, Kerem Halıcıoğlu and Aslı Garagon Doğru from Geodesy Department for their support and friendship.

I wish to express my deepest gratitude to my mother and my husband for their unlimited encouragement and patient during this study.

I dedicate this thesis to my daughters.

ABSTRACT

Hydrographic Survey is the science which deals with the measurement and description of the physical features of bodies of water and scientific mapping of the sea bed for navigation while bathymetric survey is related to topography of seafloor. The difference between land surveying and bathymetric survey is not being able to see the sea surface during observations, so collected data entirely rely on remote measurements.

Early tools used at very beginning were very slow and eventually they replaced by modern techniques such as optical systems, acoustic and satellites. Each method is appropriate for different applications, for instance manual techniques can be preferred at construction applications while aerial photography may be suitable method in extremely shallow water. Thus, different techniques are explained according to surveying type. In addition to depth values, one must define also the point position that is distance measurement. There are several ways of distance measurement for different purposes. On the other hand all vertical and horizontal data have a meaning when they represented in a way that in common use. Coordinate systems are used to display measuring data in an understandable form. Consequently, depth measurement, point positioning and mapping are main stages of bathymetric survey and they thoroughly explained in this thesis with an example study.

Living in country of which three sides are sea, it is inevitable solution to benefit from water resources for transportation. Water resources of the world compared to terrestrial resources are offering economical solution for all types of transportation for comfort and speed. For this reason The Marmaray Project which is a rail line project between the European and Anatolian sides of Istanbul, linking two continents by an under Bosporus tunnel, undertaken to meet the transportation demand of Istanbul City. Application section of this thesis is a part of that significant project.

ÖZET

Dörtte üçü sularla kaplı olan yeryüzünde hızla artan dünya nüfusunun temel ihtiyaçlarını sadece karasal kaynaklardan sağlamaya çalışmak artık yeterli olmamaktadır. Denizlerde bulunan rezervlerin önemli miktarlarda oluşu, taşımacılık alanında hız ve konfor gibi avantajlara sahip olması gibi sebepler araştırmaları denizlere doğru yöneltmiş ve hidrografik çalışmaların sayısı dolayısıyla deniz tabanı haritalarının yapımına yönelik projeler hızla artmaya başlamıştır.

Hidrografik ölçmeler suyun dinamik yapısı, deniz dibi yapısının bilimsel haritalaması gibi çalışmaları içerirken batimetrik ölçmeler deniz dibi topografyasının belirlenmesi ve haritalanması çalışmaları için gerçekleştirilmektedir. Karasal ölçmeler ile deniz ölçmeleri arasındaki en önemli farklardan biri gözlemlenen yüzeyin doğrudan görülemiyor olması nedeniyle ölçmeler uzaktan yapılmasıdır. Eskiden kullanılan klasik derinlik ölçme aletleri ile yapılan ölçmelerdeki doğruluklar yeterli olmayınca fotografik, akustik ve uzay sistemleri gibi yeni yöntemler ve modern aletler geliştirilmiştir. Çalışma alanının ve projenin türüne göre farklı aletler kullanılmaktadır. Bu tez çalışmasında yakın kıyı alanlarında yapılan batimetrik ölçme tekniklerinin yanı sıra diğer yöntemlere de kısaca değinilmiştir.

Çalışma alanının batimetrik haritasını yapabilmek için derinlik bilgisinin yanı sıra konum bilgisine de ihtiyaç duyulmaktadır. Konum belirleme yöntemleri açıklanmış, elde edilen üç boyutlu koordinatları anlamlı bir çizim ortamına aktarabilmek için gerekli olan koordinat sistemlerine de değinilmiştir.

Son olarak ülkemizde deniz dibi haritalaması ve inşaatı açısından oldukça önemli bir yere sahip olan Marmaray Tüp Geçit Projesi dahilinde yapılan batimetrik çalışma sunulmuştur. Batırma tüplerinin inşa edildiği Demiryolları, Limanlar ve Hava Meydanları İnşaatı Genel Müdürlüğü (DLH) Tuzla Limanı'nda gerçekleştirilen bu çalışmada batırma tüplerinin inşası bittikten sonra indirileceği denizin derinliğinin belli bir değerin altında olması gerektiğinden su altı kaya kırma ve çıkarma çalışmalarını yönlendirmek için batimetrik ölçmeler tekrarlanmaktadır.

TABLE OF CONTENTS

ACKNOWLEDGEMENT iii
ABSTRACT iv
ÖZET v
LIST OF FIGURES ix
LIST OF TABLES xii
LIST OF SYMBOLS xiv
1. INTRODUCTION 1
2. OVERVIEW OF BATHYMETRIC SURVEY 3
2.1. Bathymetric Surveying Types 4
2.2. Variation Effects in Bathymetric Survey 6
2.2.1. Tidal Variation 6
2.2.2. Water Quality 8
2.2.3. Atmospheric Effects 9
2.2.4. Position Accuracy 9
3. POSITIONING METHODS 11
3.1. Optical Methods 11
3.2. Electro-optic Methods 11
3.3. Acoustic Methods 12
3.4. Inertial Positioning Methods 14
3.5. Satellite Methods 15
3.5.1. Satellite Laser Ranging 16
3.5.2. Lunar Laser Ranging 16
3.5.3. Doppler Orbitography by Radiopositioning Integrated on Satellite . 17
3.5.4. Very Long Baseline Interferometry 19
3.5.5. Global Navigation Satellite System 20
3.5.6. Global Positioning System 22
3.5.6.1. Measurement Techniques for GPS 24
3.5.6.2. Sources of Error 25
3.5.6.3. Kinematic GPS 26
3.5.6.4. Differential GPS 28

4. DEPTH MEASUREMENT TECHNIQUES 30
4.1. Manual Depth Measurement Techniques 30
4.2. Modern Depth Measurement Techniques 32
4.2.1. Remote Sensing 32
4.2.2. Aerial Photography 33
4.2.3. Airborne Laser – Light Detection and Ranging 34
4.3. Acoustics 35
4.3.1. Types of Echosounders 35
4.3.1.1. Single Beam Echosounder 35
4.3.1.2. Multi Beam Echosounder 37
4.3.1.3. Side Scan Sonar 38
4.3.1.4. Split Beam Echosounder 39
4.3.2. Instruments of an Echosounder 42
4.3.2.1. Echosounder 42
4.3.2.2. Transducer 43
4.3.3. Sound Velocity Measurement in Sea Water 43
4.3.3.1. Sound Velocity by Equations 44
4.3.3.2. Sound Velocity by Bar Check Method 44
4.3.4. Depth Measurement Sources of Errors and Corrections 45
4.3.4.1. Transducer Depth Correction 45
4.3.4.2. Velocity Correction 46
4.3.4.3. Slope Correction 46
4.3.4.4. Calibration Correction 46
4.3.4.5. Heave Correction 46
4.3.4.6. Pitch and Roll Correction 47
5. COORDINATE SYSTEMS 48
5.1. Basic Coordinate Systems 49
5.2. Earth-based Locational Reference System 50
5.2.1. Reference Ellipsoid 50
5.2.2. Geodetic Datums 51
5.3. Global Coordinate Systems 53
5.3.1. Latitude, Longitude, Height 53
5.3.2. Earth Centered Earth Fixed Cartesian Coordinates 54

5.3.3. Universal Transverse Mercator 56

5.3.4. Military Grid Reference System 57

5.3.5. World Geographic Reference System 58

5.4. Regional Systems 59

5.4.1. Turkish National Fundamental GPS Network 59

5.4.2. International Terrestrial Reference Frame 60

5.4.3. World Geodetic System 1984 61

5.4.4. European Datum Coordinate System 1950 61

6. APPLICATION 63

6.1. Survey Area 64

6.2. Topographic Surveying Activities 64

6.3. Bathymetric Surveying Activities 70

6.4. Evaluation of Bathymetric Data 78

7- CONCLUSION 81

APPENDIX 82

REFERENCES 95

REFERENCES NOT CITED 98

LIST OF FIGURES

Figure 2.1. Acoustic depth measurement 4

Figure 3.1. Electromagnetic distance meter 11

Figure 3.2. Schematic diagram of INS mechanism 14

Figure 3.3. SLR system operating in Greenbelt 16

Figure 3.4. The Apollo 11 laser ranging retroreflector 17

Figure 3.5. Laser beam aimed at Moon by a telescope 17

Figure 3.6. Jason-1 Satellite instrumentation schematic 18

Figure 3.7. Jason-1 measurement system 19

Figure 3.8. 76m Lovell radio telescope 20

Figure 3.9. GLONASS Satellite 21

Figure 3.10. Stations range accuracy 22

Figure 3.11. A schematic diagram of the GPS constellation 23

Figure 3.12. Navstar GPS Satellite 24

Figure 3.13. Pseudo random codes 25

Figure 4.1. Lead line depth measurement 31

Figure 4.2. Sounding pole depth measurement 31

Figure 4.3. The way of sound 36

Figure 4.4. Basic echosounder operation 36

Figure 4.5. Sound way of side scan sonar 39

Figure 4.6. Acoustic seafloor characterization techniques 40

Figure 4.7. Sub-bottom Profiler 41

Figure 5.1. Cartesian coordinates in a plane 49

Figure 5.2. Three-dimensional cartesian coordinates 49

Figure 5.3. Ellipsoidal Parameters 50

Figure 5.4. Earth surfaces 52

Figure 5.5. Equator and prime meridian 53

Figure 5.6. Geodetic latitude, longitude and height 54

Figure 5.7. Earth centered earth fixed X, Y, Z coordinates 55

Figure 5.8. Universal transverse mercator (UTM) system 56

Figure 5.9. UTM display 57

Figure 5.10. Military grid reference system (MGRS) 58

Figure 5.11. World geographic reference system 59

Figure 6.1. The Marmaray Project 63

Figure 6.2. Project area in D.L.H. harbor 64

Figure 6.3. Primary and secondary control points of D.L.H. harbor 67

Figure 6.4. D.L.H. harbor map 69

Figure 6.5. Tide gauge system 70

Figure 6.6. Bathymetric survey system 71

Figure 6.7. Dimensions of transducer's parts 72

Figure 6.8. Bathymetric survey lines 73

Figure 6.9. Bathymetric survey lines in D.L.H. harbor 74

Figure 6.10. Survey boat 75

Figure 6.11. Survey system in survey boat 75

Figure 6.12. GPS receiver at shore 76

Figure 6.13. Contour line map of survey area 79

Figure 6.14. Wireframe drawing of D.L.H. harbor 80

Figure 6.15. Seafloor topography of D.L.H. harbor 80

LIST OF TABLES

Table 2.1. Factors changing sea level 7

Table 2.2. Sound velocity values 9

Table 2.3. Expected depth accuracy for bathymetric survey 10

Table 2.4. Expected accuracy for bathymetric positioning 10

Table 3.1. Acoustic properties of air and water 13

Table 3.2. GPS sources of error 26

Table 3.3. GPS survey methods 27

Table 4.1. Accuracy according to frequency of sound wave for depth 37

Table 5.1. Selected reference ellipsoids 51

Table 5.2. Geodetic base for Turkey 62

Table 5.3. Parameters of reference systems of Turkey 62

Table 6.1. Coordinates of primary control points 65

Table 6.2. Trimble 3603 DR total station technical specifications 66

Table 6.3. Coordinates of secondary control points 66

Table 6.4. Trimble 5503 DR total station technical specifications 68

Table 6.5. Trimble 5700 RTK GPS System Technical Specifications 68

Table 6.6. Raytheon DE719E Fathometer Technical Specifications 71

Table A.1. Table A.1. Coordinates of Detail Points in DLH Harbor, Tuzla 83

LIST OF SYMBOLS

V	Velocity
d	Distance
t	Time
c	Sound velocity
V_0	Sound velocity at 0 °C, 3.5 per cent salinity, 750 mmHg
V(t)	Polynomial of temperature
V(p)	Polynomial of pressure
V(s)	Polynomial of salinity
V(stp)	Polynomial of stp
S	Water Salinity
IHO	International Hydrographic Organization
C(T)	Speed of sound in air as a function of temperature in inches/sec
T	Temperature
L	Latitude
α_e	Transducer width
β_e	Slope of seafloor
a	Semi major axis
b	Semi minor axis
f	Flattening the ellipsoid
e	eccentricity
λ	Geodetic longitude
ϕ	Geodetic Latitude
h	Geodetic height
N	Radius of curvature in the prime vertical
EDM	Electromagnetic Distance Meters
DGPS	Differential Global Positioning System
RTK	Real Time Kinematic
GPS	Global Positioning System
INS	Inertial navigation system

SLR	Satellite Laser Ranging
LLR	Lunar Laser Ranging
DORIS	Doppler Orbitography by Radiopositioning Integrated on Satellite
VLBI	Very long baseline interferometry
GLONASS	Global Navigation Satellite System
NAVSTAR	Navigation Satellite Timing and Ranging
SONAR	Sound Navigation and Ranging
LIDAR	Light detection and ranging
GIS	Geographical information system
UTM	Universal Transverse Mercator
TUTGA	Turkish National Fundamental GPS Network
TUDKA	Turkish National Vertical Control Network
TKGM	General Directorate of Land Registry and Cadastre
WGS	World Geodetic System
ITRF	International Terrestrial Reference Frame
ED	European Datum
GRS	Geodetic Reference System
D.L.H.	General Directorate of Railways, Harbors and Airports Construction

1. INTRODUCTION

Surveying is the method of determining accurately points and lines of direction on the Earth's surface and preparing maps or plans from collected data. Boundaries, areas, elevations, construction lines, and geographical or artificial features are determined by the measurements which are horizontal and vertical distances, angles and by computations based on geometry, trigonometry and geomorphometry.

Hydrographic Survey which is sub-category of Geodetic Survey is the science which deals with the measurement and description of the physical features of bodies of water and scientific mapping of the sea bed for navigation. Hydrographic survey is the process of gathering information about navigable waters for the purposes of safe navigation of vessels. It strictly applies to survey of any navigable waters, including lakes and rivers, but it is most commonly applied to marine navigation. A hydrographic survey may be conducted to support a variety of activities: nautical charting, port and harbor maintenance (dredging), coastal engineering (beach erosion and replenishment studies), coastal zone management, and offshore resource development. The one data type common to all hydrographic surveys is “water depth”.

Increasing population and demand for new natural resources such as natural gas, oil, nutrition and need for people to communicate and travel quickly over vast distances make the studying the oceans inevitable in recent years. Almost ¾ of the world surface is water and it is known that natural resources capacity can supply the world’s energy needs for a couple of decades. On the other hand transportation through water resources compared to terrestrial ones is more comfortable, economical and quick solution. To be able to make use of water resources, the scientists and engineers need to determine and understand geographical features and shape of the seafloor through the created hydrographic maps.

Hydrographic or bathymetric surveys are similar to the classical land surveying methods in terms of positioning process, depth measurement, corrections, mapping steps. The most important differences between land surveying and hydrographic survey are not being able to see the surface and continuous motion of water surface (Carleton and Cook, 2000) [1]. In order to get great accuracy from measurements, scientists and engineers have designed equipments which are used according to survey type.

2. OVERVIEW OF BATHYMETRIC SURVEY

Bathymetry is the measurement of the depths of water bodies from the water surface and charting of the sea floor using these water depth measurements (Ingham, 1975) [2]. It can be seen as marine equivalent to topography. Producing maps of the seafloor has always been a particular challenge to humankind. On land, surveyors can see important surface features and know they are shown accurately on the finished topographic map but underwater surfaces are not visible to the hydrographic surveyor, who must rely entirely on remote measurements.

Oceanographers have discovered the shape of the ocean floor by measuring the depth of the ocean in many places. Early tools included lead weights, lowered on marked ropes or cables to the ocean floor. From such depth readings, scientists gradually built a picture of the ocean floor they could not see. These methods were very slow and eventually were replaced by modern techniques such as acoustic, optical systems and satellites.

Bathymetric surveys use sound navigation and ranging (sonar) systems to collect depth information. These systems are based on the principle that when a sound signal is sent into the water it will be reflected back when it strikes an object. An instrument, called a transducer, sends a sound pulse straight down into the water. The pulse moves down through the water and bounces off the seafloor. The transducer also picks up the reflected sound. Computers precisely measure the time it takes for the sound pulse to reach the bottom and return. The water depth is calculated by knowing how fast sound travels in the water. This method of seafloor mapping is called echo sounding.

$$V = d / t \tag{2.1}$$

Where V: Velocity, d: Distance, t: Time

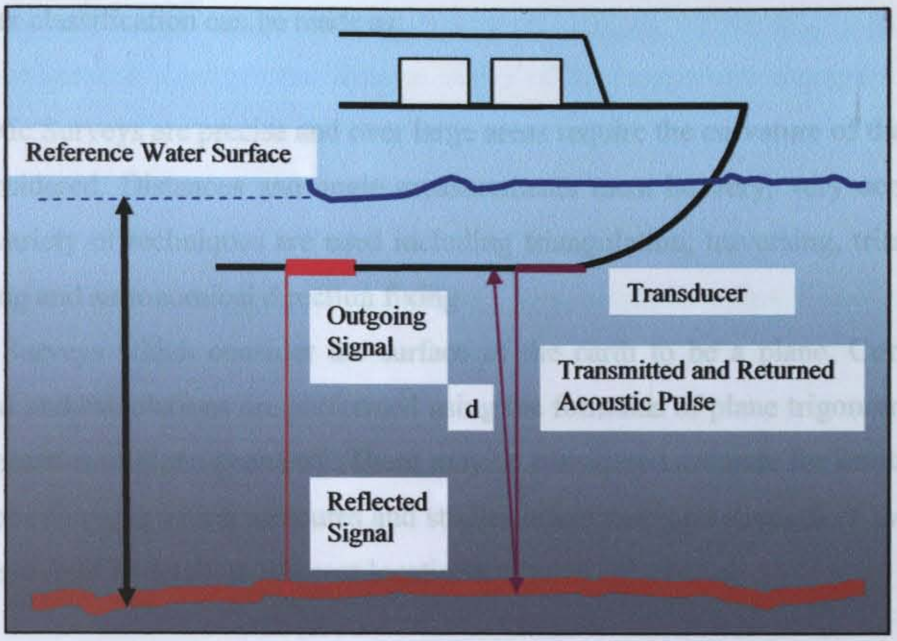

Figure 2.1. Acoustic depth measurement

Bathymetric or hydrographic measurements are conducted similar to land surveys. Positioning process has to be done for establishing control network, determining the coastline and positioning the points on horizontal plane.

2.1. Bathymetric Surveying Types

The techniques used for surveying and land measurement are dependent upon the type of survey being conducted. A simple classification of types of survey is:

I. Land Surveys, which fix property lines, calculate land areas and assist with the transfer of real property from one owner to another.
II. Engineering Surveys, which collect the data needed to plan and design engineering projects. The information ensures the necessary position and dimension control on the site so that the structure is built in the proper place and as designed.
III. Informational Surveys obtain data concerning topography, drainage and man made features of a large area. This data are portrayed as maps and charts.

Another classification can be made as:

I. Geodetic Surveys are precise and over large areas require the curvature of the earth to be considered. Distances and angle measurements must be very, very accurate. A wide variety of techniques are used including triangulation, traversing, trilateration, levelling and astronomical direction fixing

II. Plane Surveys which consider the surface of the earth to be a plane. Curvature is ignored and calculations are performed using the formulas of plane trigonometry and the properties of plane geometry. These may be considered accurate for limited areas.

III. Magnetic Surveys which measures and studies orientation and strength of the Earth's magnetic field in detail at different locations.

Sub-categories of the major classes provide more insight into the various fields of surveying as follows:

I. Property Surveys, determine boundary lines, property corners, rights-of-way provide data necessary for the preparation of land sub-divisions.

II. Cadastral Surveys are executed by the Government in connection with the disposal of vast areas of land known as the public domain.

III. Route Surveys are necessary for the design and construction of various engineering projects such as roads, railways, pipelines, canals and power lines.

IV. Industrial Surveys or optical metrology, are used in the aircraft and other industries where very accurate dimensional layouts are required.

V. Topographic Surveys are performed to gather data necessary to prepare topographic maps. These are multicolor contour maps portraying the terrain; and rivers; highways, railways, bridges and other man-made features.

VI. Hydrographic Surveys map the shorelines of bodies of water; chart the bottom of streams, lakes, harbors and coastal waters; measure the flow of rivers; and assess other factors affecting navigation and water resources. The sounding of depths by radar is involved in this type of survey.

VII. Mine Surveys determine the position of underground works such as tunnels and shafts, the position of surface structures and the surface boundaries.

VIII. Aerial Surveys use photogrammetry or remote sensing to produce a mosaic of matched vertical photographs, oblique views of landscape and topographic maps drawn from the photographs.

IX. Construction Surveys fix elevations, horizontal positions and dimensions for construction projects.

X. Control Surveys provide basic horizontal and vertical position data. These are called datum. For most surveying work the vertical position of points in terms of height above a curved reference surface is mean sea level (Techniques of surveying, Queensland Government Web Site).

2.2. Variation Effects in Bathymetric Survey

Bathymetric measurements are directly relative to sea, weather and land conditions. Meteorological, oceanographic and geographical situations are taken into account while evaluating bathymetric data.

2.2.1. Tidal Variation

All depth measurements are relative to the surface of the water but the surface of the rivers, lakes and oceans is not a constant elevation. Measurements must be adjusted to compensate for tidal and seasonal variations in water depth measurements. In wavy conditions water surface changes influence the data being collected. In all cases surface of the water is adjusted to constant datum. If the water body is not affected by tidal variations, the depth is referenced to another datum.

The effects in sea surface and level can be grouped as (Hekimoğlu and Şanlı, 1993) [3]:

I. Meteorological Effects: Atmospheric pressure, changes in temperature and wind.

II. Oceanographic Effects: Streams and density of water.

III. Land level changes: Bathymetric measurements are adjusted to land datum. Consequently, vertical movements on land level may cause the sea level changes.

IV. Astronomical Tides: The most important effect which changes sea level up to 10m.

Factors changing sea level are tabled below (Sea Level Rise, 2006, Wikipedia).

Table 2.1. Factors changing sea level

Periodic sea level changes		
Short Term (Periodic) Causes	Time Scale P=Period	Vertical Effect
Astronomical Tides	6-12 h P	0.2-10+ m
Long Period Tides		
Rotational Variations	14 month P	

Meteorological and oceanographic fluctuations		
Short Term (Periodic) Causes	Time Scale	Vertical Effect
Winds	1–5 days	Up to 5 m
Evaporation and precipitation	Days to weeks	
Ocean surface topography	Days to weeks	Up to 1 m

Seasonal variations		
Short Term (Periodic) Causes	Time Scale	Vertical Effect
River runoff/floods	2 months	1 m
Seasonal water density changes (temperature and salinity)	6 months	0.2 m

Seiches		
Standing Waves	Minutes to hours	Up to 2 m

Earthquakes		
Tsunamis	Hours	Up to 10 m
Abrupt change in land level	Minutes	Up to 10 m

If there is a mareograph station near the survey area, tide variation value is taken from this station, however it is not common used method. Generally sea level surface height is taken from local stations by the cost of the survey area.

2.2.2. Water Quality

Acoustic depth measurement instruments send sound waves through the water, sound pulses to the surface than turns to receiver. Water temperature, salinity, pressure and density are the factors which affect the velocity of sound. Although water is a good condition for sound waves, it is not good for electromagnetic waves. The shortest way to sea floor is found from multiplying velocity by travel time of sound wave, thus, temperature, salinity, pressure and density parameters must be taken in to account.

I. Temperature: Changes in temperature influence sound velocity five times more than the other factors. It varies with location, depth and currents. Sound velocity can vary between 1390-1650 m/s but at 15 °C and 3.2 per cent salinity it is 1500 m/s.
II. Salinity: It is expressed the amount (weight) of all minerals and elements found in 1000 grams water. Salinity change in deep sea is less than nearshore.
III. Density: Ratio of the mass of water (kg) occupied in a volume of 1 m^3. Generally density of sea water accepted 1.026 gr/c m^3, but it increase with decreasing temperature, increasing salinity and depth.
IV. Pressure: Water pressure differs at various depths, that is, pressure increases the deeper the sea becomes.

Sound velocity below the sea has been formulated by Wilson as a function of temperature, depth and salinity (Doğan and Alpar, 1994):

$$c = V_0 + V(t) + V(p) + V(s) + V(stp) \qquad (2.2)$$

where c: Velocity, V_0: Sound velocity at 0 °C, 3.5 per cent salinity, 750 mmHg, V(t): Polynomial of temperature, V(p): Polynomial of pressure, V(s): Polynomial of salinity, V(stp): Polynomial of stp

For general use, formula has been made easier as;

$$c = 1449.2 + 4.6t - 0.055t^2 + 0.00029t^3 + (1.34-0.01t)(s-35) + 0.016d \qquad (2.3)$$

where c: Velocity of sound in the sea, t: Water temperature (0-35 °C), d: Depth from sea surface, s: Water salinity (0-4.5 per cent)

Table 2.2. shows the sound velocity values at different temperature and in different depths (Köprülü, 2006) [4].

Table 2.2 Sound velocity values

Water Temperature °C	Sound Velocity (m/s) at 0 m	Sound Velocity (m/s) at 100 m	Sound Velocity (m/s) at 250 m	Sound Velocity (m/s) at 500 m
0 °C	1475.00	1476.50	1478.90	1482.70
5 °C	1485.10	1486.70	1489.10	1493.00
10 °C	1495.90	1497.50	1499.90	1503.90
15 °C	1506.70	1508.30	1510.70	1514.80
20 °C	1516.90	1518.60	1521.00	1525.20

2.2.3. Atmospheric Effects

Temperature, pressure, wind, humidity, climate changes are the factors that influence all types of positioning and depth measuring techniques. For instance, variations in atmospheric pressure affect sea surface heights via the inverse barometer effect, that is, the static response of the sea to atmospheric pressure. Satellite positioning system measurements affected by atmospheric factors which reduce the signal speed. One of them is Ionospheric Effect which is free electron movement influencing electromagnetic propagation and Tropospheric Effect signal delays affected by temperature, relative humidity and pressure. Thus, temperature and pressure corrections should be taken in to account if electromagnetic instruments are used.

2.2.4. Position Accuracy

Due to the unstable position of vessel, bathymetric measurements can not be repeated. Therefore position accuracy from bathymetric survey is lower than land survey's.

Generally nearshore bathymetry accuracy expected better than offshore bathymetries (Aydın *et al.*,2005) [5]. Hydrographic IHO Standards are shown in Table 2.3 (www.hypack.com). In addition IHO's, there are other accuracy standards for different surveying activities which is given in Table 2.4 (Alkan, R. M., 2001) [6].

Table 2.3. Expected depth accuracy for bathymetric survey

ORDER	Special	1	2	3
Example of Typical Areas	Harbors, berthing areas, and associated critical channels with minimum underkeel clearances	Harbors, harbor approach channels, recommended tracks and some coastal areas with depths up to 100m	Areas not described in Special Order and Order 1, or areas up to 200m water depth	Offshore areas not described in Special Order, and Orders 1 and 2
Horizontal Accuracy (95 per cent Confidence Level)	2m	5m + 5 per cent of depth	20m + 5 per cent of depth	150m + 5 per cent of depth
Depth Accuracy for Reduced Depths (95 per cent Confidence Level) $= \pm\sqrt{[A^2+(BxD)^2]}$ where D=Depth	A=0,25m B=0.0075	A=0,5m B=0.0013	A=1,0m B=0.0023	A=1,0m B=0.0023

Table 2.4. Expected accuracy for bathymetric positioning

Possible Application Area	Accuracy
Geodynamic researches for ocean floor motion	<±0.1 m
Deformation studies	<±0.1 m
Large scale hydrographic charting	±1.3-1m
Sea floor control points	±1m
Drilling holes	±3-5m
Marine cadastre	±5m
Pipelines	±1-8m
Continental shelf and territorial boundaries	±1-10m
Marine mining	±10m
Oil and gas	±10-20m
Oceanographic and geophysical studies	±50-100m

3. POSITIONING METHODS

Positioning methods used for bathymetric survey can be grouped in to 5 categories.

3.1. Optical Methods

Optical method has generally used for distance measurements. Disadvantage of optical measuring is that clear line of sight between the instrument and the measured points is essential. That is why optical methods can be used at very nearshore. Additionally, angles are measured by theodolite but they have been replaced by the use of total stations.

3.2. Electro-optic Methods

Electromagnetic Distance Meters (EDM) were developed after the world war II and the first EDM, Geodimeter, using visible light was produced in Sweden in 1953 (Özgen and Algül, 1977) [7]. Microwave radiation EDM, Tellurometer, was produced in South Africa in 1954. Infrared EDMs have been using since 1960s. The first aim of development of EDM was to measure the distance between land points and the points at sea vessel.

Electromagnetic Distance Measurement Equipments measure distance using light and radio waves and the distance is calculated either from the time difference between a transmitted pulse and a return pulse or the phase difference between a transmitted and a reflected beam of radiation.

Figure 3.1. Electromagnetic distance meter

Electromagnetic distance measuring equipments use three different wavelength bands (Plane Surveying Equipments, Department of Geomatics Web Site, The University of Melbourne):

I. Microwave Systems
   - Range up to 150 km
   - Wavelength 3 cm
   - Not limited to line of sight
   - Unaffected by visibility
II. Light wave Systems
   - Range up to 5 km
   - Visible light, lasers
   - Distance reduced by visibility
III. Infrared Systems
   - Range up to 3 km
   - Limited to line of sight
   - Limited by rain, fog, other airborne particles

Accuracy of the measurements are in order of ±0.005m + 1:10000 x distance. The combination of EDM and electronic theodolite called as Total Station.

3.3. Acoustic Methods

Acoustic positioning system works by using pulses of sound to measure distance underwater from a transmitter (transducer) to receiver (transponder) (Algül, 1983) [8].The pulse activates the transponder, which responds immediately to the vessel transducer. The transducer, with corresponding electronics, calculates an accurate position of the transponder relative to the vessel. Comparative acoustic properties of air and water is shown in Table 3.1 (Fundamentals of Electro acoustics, www.massa.com)

Table 3.1. Acoustic properties of air and water

	Temperature (°C)	Density (kg/m3)	Velocity (m/sec.)	Acoustic Impedance (MKS Rayls)
Fresh Water	20	1000	1480	1.48×10^6
Sea Water 35 ppt salinity	13	1026	1500	1.54×10^6
Air	0	1.29	332	428
Air	20	1.21	343	415

Wave length of changes as a function of both speed of sound and frequency:

$$\lambda = c / f \qquad (3.1)$$

where ; λ: Wavelength, c: Speed of sound, f: Frequency

Speed of sound in air as a function of temperature:

$$C(T) = 13{,}044\sqrt{1+T/273} \qquad (3.2)$$

where ; C(T): speed of sound in air as a function of temperature in inches/sec. T: the temperature of air in °C

Generally four types of base line acoustic measurement used in hydrographic or bathymetric surveys:

I. Super Short Base Line Positioning: The calculation of positioning is based on range and on vertical and horizontal angle measurements from a single multi element transducer. The system provides three dimensional transponder positions relative to the vessel.

II. Short Base Line Positioning: The calculation of positioning is based on range and on vertical and horizontal angle measurements from a minimum of three hull mounted transducers. The system provides three dimensional transponder positions relative to the vessel.

III. Long Base Line Positioning: The calculation of positioning is based on range measurements only. The vessel is positioned relative to a calibrated array of transponders.

IV. Multi-User Long Base Line Positioning: Hydro acoustic positioning system.

The systems are in common use in the offshore industry and by the military but are not in common nearshore surveys.

3.4. Inertial Positioning Methods

Inertial positioning system known as Inertial Navigation System originally developed in 1960's for missile guidance by the US Army and after an extensive evolutionary process has been introduced into civil aviation.

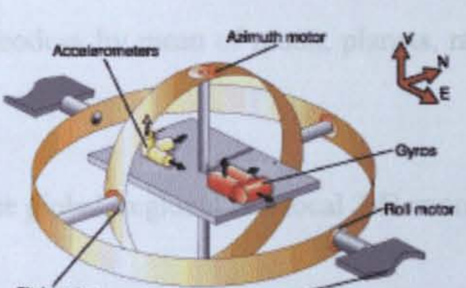

Figure 3.2. Schematic diagram of INS mechanism

Free objects have linear (x, y, z) that means position and rotational (theta, psi, phi) that means attitude degrees of freedom. Inertial navigation system uses these two principles, gravity and momentum. Gyroscope (device which measures rotational velocity) and accelerometer (device which measure acceleration) can measure the change in angle on various axis and hence using electronic circuitry can calculate the position relative to the start, thus they cannot determine their initial location, just the change relative to it. Figure 3.2 shows the schematic diagram of INS mechanism. (Pakistani Aviation, 2005)

To derive accurate sub-sea cartography, reliable attitude and position information is needed (Chapelon and Kammerer, 2005) [9]. Consequently, precise motion sensors and positioning systems have been implemented to meet hydrographic measurement requirements. By using INS the heading accuracy could be better than 0.02 deg and the roll or pitch accuracy could be better than 0.01 deg. Inertial Navigation Systems can be used as an autonomous system or integrated with Differential Global Positioning System (DGPS) or Real Time Kinematic (RTK) GPS or Doppler Velocity Log (DVL) to get very high precision but cost of such configuration is so high, integrated systems are just used in military (Ingham, 1992) [10].

3.5. Satellite Methods

Geodesy is the science of the measurement and mapping of the Earth's surface including gravity field and ocean floor. Satellite geodesy comprises the observational and computational techniques which allow the solution of geodetic problems by the use of precise measurements to, from or between artificial satellites.

Space geodesy is the geodesy by mean of moon, planets, ratio stars and quasars. Its basic problems are:

I. Determination of precise global, regional and local 3-D coordinates,
II. Earth's gravity field,
III. Measuring and modeling of geodynamical phenomena that is, polar motion, earth rotation, crustal deformation.

First artificial satellite Sputnik was launched in 1957, than earth's flattening from satellite data was found in 1958 as f=1/298.3. After developments of basic methods for the satellite computation and observation between the years 1958-1970, scientific projects and new observation techniques SLR, TRANSMIT and satellite altimetry have developed during 1970-1980. Operational use of satellite techniques in geodesy, geodynamics and surveying (first results with GPS) was developed between the years 1980-1993. Exhaustive use of Global Positioning System (GPS) serves to space based precise measurement techniques since 1993. Today space geodesy techniques listed and explained briefly below:

3.5.1. Satellite Laser Ranging

Satellite Laser Ranging (SLR) measures the time intervals required for pulses emitted by laser transmitter to travel to a satellite and return to the transmitting site. The range or distance between the satellite and the observing site is approximately equal to one half of the two-way travel time multiplied by the speed of light. It is the most accurate technique currently available to determine the geosentric position of an earth satellite, allowing for the precise calibration of radar altimeters and separation of long term instrumentation of drift secular changes in ocean topography. In space geodesy, scientific achievements and applications using SLR data have been obtained and developed in many fields: orbitography, Earth's rotation and geocentric reference frame, geodynamics, determination of long wave length of the gravity field, and of the geosentric gravitational constant (GM).

Figure 3.3. SLR system operating in Greenbelt, Maryland

3.5.2. Lunar Laser Ranging

Lunar Laser ranging (LLR) measures the round-trip travel times of light pulses between stations on the earth and four retroreflectors on the surface of the moon. Retroreflectors were planted on the moon on July 21, 1969, by the crew of the Apollo 11. Since then, the distance between the Earth and the moon has been measured repeatedly over a period of more than 35 years. In addition its value for lunar sciences and the theory of gravitation, LLR is a key International Earth Rotation and Reference System Service

(IERS) technique for connecting reference frames. (LLR Image courtesy of McDonald Observatory, Texas).

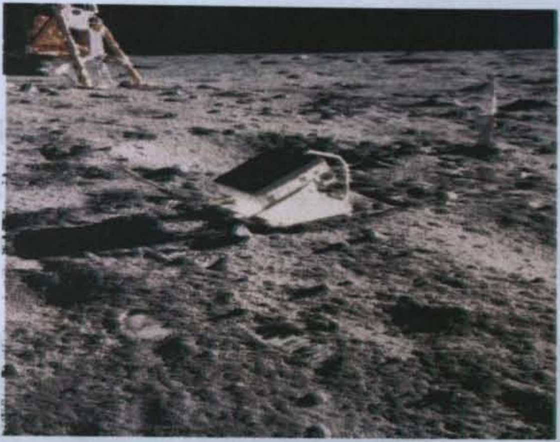

Figure 3.4. The Apollo 11 laser ranging retroreflector

Figure 3.5. Laser beam aimed at Moon by a telescope

3.5.3. Doppler Orbitography by Radiopositioning Integrated on Satellite

Doppler Orbitography by Radiopositioning Integrated on Satellite (DORIS) is a dual frequency Doppler system that can be included as a host experiment on various space missions, Spot-2, -3, -4, -5, Topex/Poseidon, Jason, ENVISAT and CryoSat in the future. On contrary to most navigation systems, DORIS is based on an uplink device: the receiver is on board the satellite while the transmitters are on the ground. The Doris system is based on the principle of the Doppler Effect. This is the effect that causes the frequency of a wave to shift when a transmitter and receiver are in motion relative to one another. Consequently, the frequency of the received signal is not the same as that of the transmitted signal. The frequency increases as the two objects get closer and decreases as they move apart. The Doris system transmits and receives radiofrequency waves. The receiver is on the satellite and the transmitters are ground beacons. Jason-1 is one of the satellites which is equipped with an altimeter, a radiometer, a laser retroreflector array, DORIS and TRSR (Figures taken from www.oceanworld.tamu.edu)

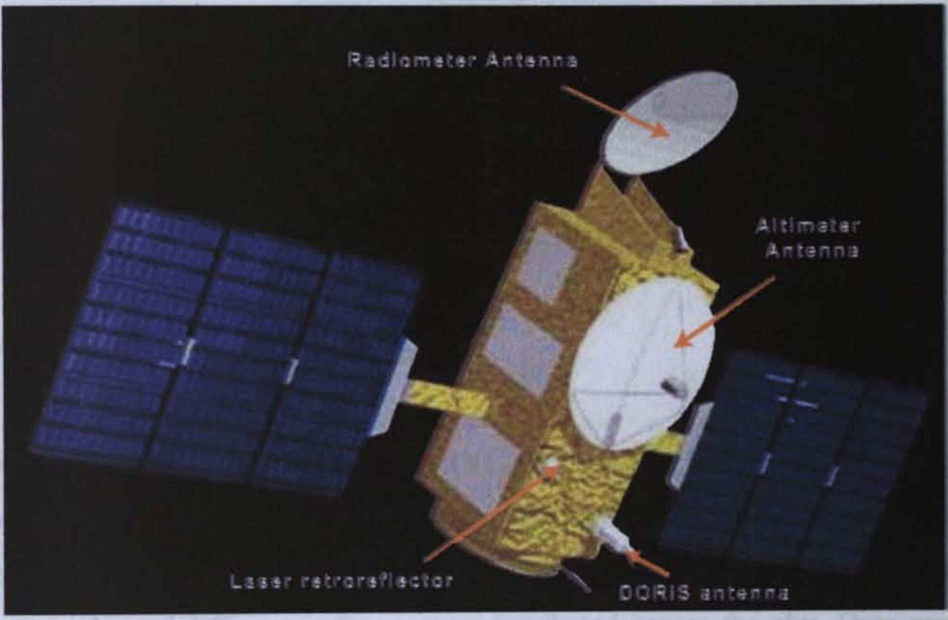

Figure 3.6. Jason-1 Satellite instrumentation schematic

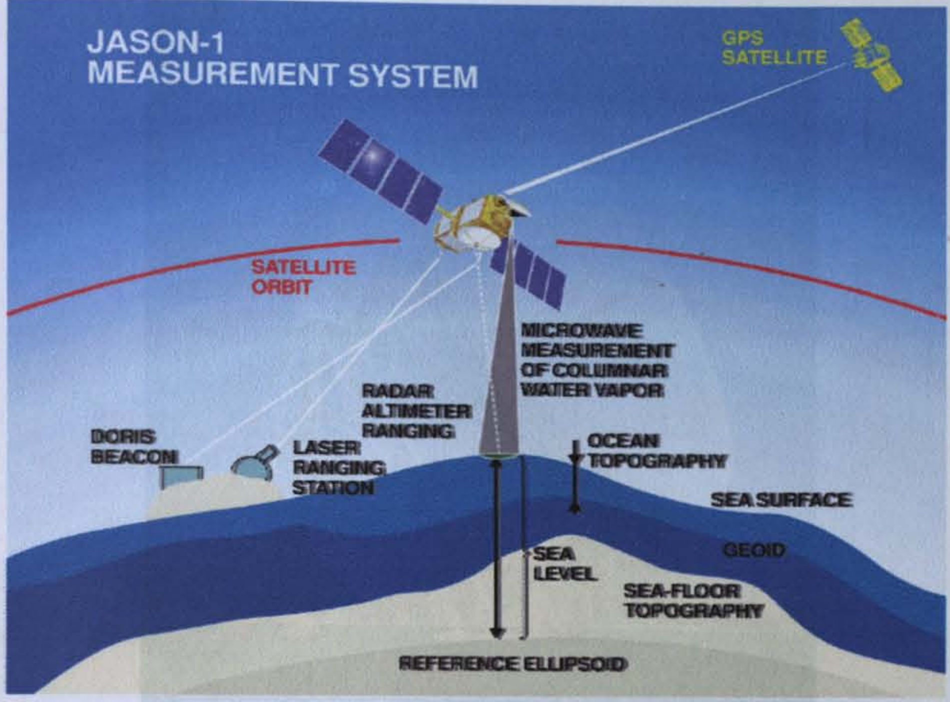

Figure 3.7. Jason-1 measurement system

3.5.4. Very Long Baseline Interferometry

Very Long Baseline Interferometry (VLBI) measures the time differences in the arrival of microwave signals from extragalactic radio sources receives at two or more radio observatories (antennas). Generally geodetic observing sessions run for 24 hours and observe a number of different radio sources distributed across the sky. Data received at each antenna in the array is paired with timing information, usually from a local atomic clock, and then stored for later analysis on magnetic tape or hard disk. The resolution achievable using interferometry is proportional to the distance between the antennas furthest apart in the array. VLBI is the only technique capable of measuring all components of the earth's orientation accurately and simultaneously.

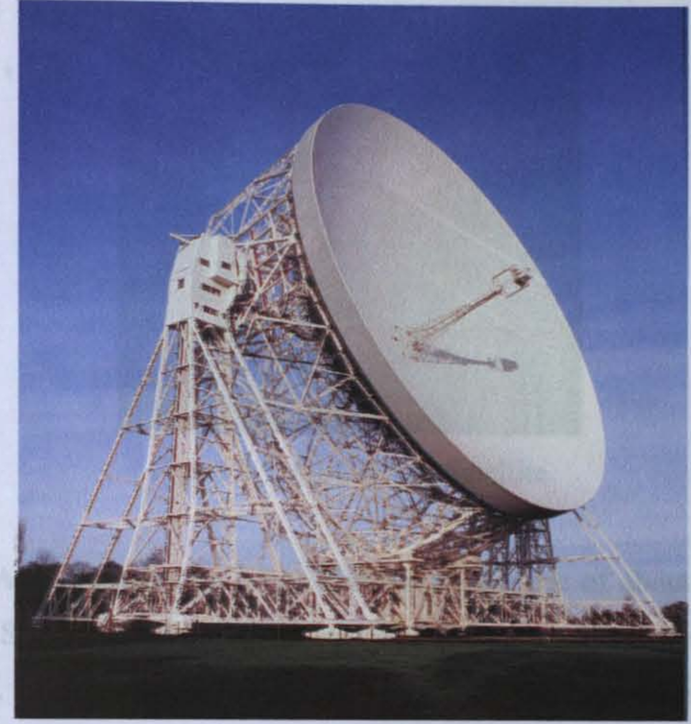

Figure 3.8. 76m Lovell radio telescope - Photo by Ian Morison

3.5.5. Global Navigation Satellite System

The Global Navigation Satellite System (GLONASS) is based on a constellation of active satellites which continuously transmit coded signals in two frequency bands which can be received by any users anywhere on the Earth's surface to identify their position and velocity in real time based on ranging measurements. GLONASS and GPS share the same principles in data transmission and positioning methods. System is managed by Russian Space Forces.

The first operational satellites went into service in December 1983. Russia continued building the GLONASS system after the old Soviet Union dissolved in the early 1990s. The system was in full operation in December 1995. After the fall of the Soviet Union, Russia has only eight satellites in operation in 2002. Economic conditions improved and 11 satellites were in operation in 2004. A total of 14 were in orbit at the end of 2005. Like the U.S. and European GPS networks, the complete GLONASS constellation was, and again in the future will be, 24 satellites (Space Today Online, 2006).

Figure 3.9. GLONASS Satellite

The GLONASS constellation orbits Earth at an altitude of about 19.100 km, a bit lower than the U.S. GPS satellites. Each satellite completes a trip around Earth every 11 hours 15 minutes. They are spaced in orbit so a user on the ground can see at least five satellites at any time (Figure 3.9 GLONASS Satellite, www.astronaytix.com).

The system offers a standard C/A positioning and timing service giving horizontal position accuracy within 55 meters and vertical position within 70 meters based on measurements from four satellite signals.

Figure 3.10 shows the range accuracy of stations (Juan, Pajares, Sanz, 1998) [11].

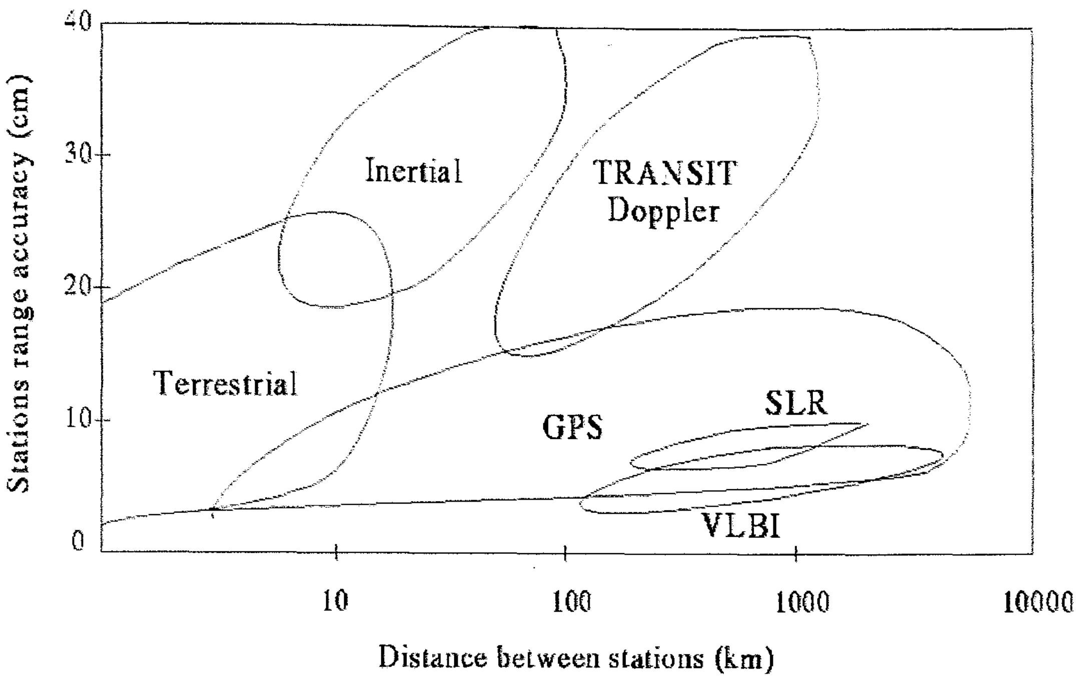

Figure 3.10. Stations range accuracy

3.5.6. Global Positioning System

The Global Positioning System (GPS) program was initiated in 1973 when the United States Air Force, Army, Navy, Marine Corps and Defense Mapping Agency decided to use their combined technical resources to develop a very accurate space based navigation system. GPS provides highly accurate time, velocity, positional data as well as it meets the common radio positioning requirements of broad spectrum of users. Depending on the mode of use and the equipment used high precision measurements can be made in geodetic applications. It is therefore utilized in geodetic programmes to supplement and strengthen the databases which are used to build models of the Earth's gravity fields, ocean tides, sea surface topography, orientation, global sea level and ocean circulation.

The Navigation Satellite Timing and Ranging (NAVSTAR) Global Positioning System (GPS) is a network of orbiting satellites that can be used to provide information on the location of a signal receiver on the earth's surface. NAVSTAR GPS was conceived as a ranging system from known positions of satellites in space to unknown positions on land, sea, in air and space. The GPS constellation consists of 24 satellites in 6 orbital planes with 4 satellites in each plane. It provides specially coded satellite signals that can be processes in a GPS receiver, enabling the receiver to compute position, velocity and time. Four GPS satellite signals are used to compute positions in three dimensions (X, Y, Z) and the time offset in the receiver clock.

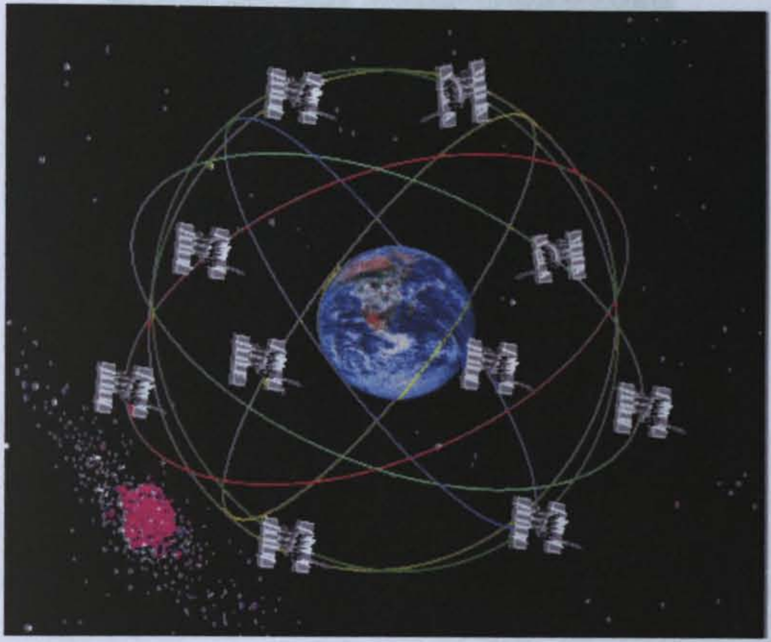

Figure 3.11. A schematic diagram of the GPS constellation

GPS System consists of three segments (Eren and Uzel, 1995) [12]:

I. Space Segment; consists of the GPS satellites which send radio signals from space.
II. Control Segment; consists of a system of tracking stations located around the world.
III. User Segment; consists of the GPS receivers and the user community. GPS receivers convert SV signals into position, velocity and time estimates.

If we know the distance from one satellite to our receiver, we know we are somewhere on the surface of a sphere of this radius distant from the satellite. If we can determine another distance from another satellite, we narrow down our possible location to somewhere on the surface where these two spheres meet. If we can determine a third distance then this gives us only two possible locations for our receiver. One of these locations is usually nonsensical (for example inside the planet) so the other location is our position. If we needed to be certain, we would determine the position from another satellite, so four distance determinations gives our location as well as eliminate clock errors in the receivers.

Figure 3.12. Navstar GPS Satellite

3.5.6.1. Measurement Techniques for GPS. GPS is based on pseudorange measurements. The pseudorange is the "distance" between the GPS satellite at some transmit time and the receiver at some receive time. GPS receiver determines the travel time of a signal from a satellite by comparing the "pseudo random code" it is generating with an identical code in the signal from the satellite. Pseudo random code is a signal with random noise-like properties. It is a very complicated but repeating pattern of 1's and O's. The receiver slides its code later and later in time until it syncs up with the satellite's code. The amount it has to slide the code is equal to the signals travel time. Two different techniques listed below:

I. Code Phase Tracking (Navigation): Code phase is one processing technique that gathers data via a C/A (coarse acquisition) code receiver, which uses the information contained in the satellite signals (pseudo-random code) to calculate positions. After differential correction, this processing technique results in 1-5 meter accuracy.

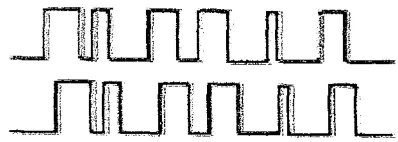

Figure 3.13. Pseudo random codes

II. Carrier Phase Tracking (Surveying): Carrier phase is another processing technique that gathers data via a carrier phase receiver, which uses the radio signal to calculate positions. The carrier signal, which has a much higher frequency than the pseudo-random code, is more accurate than using the pseudo-random code alone. The pseudo-random code narrows the reference then the carrier code narrows the reference even more. After differential correction, this processing technique results in sub-meter accuracy.

The carrier phase receivers are much more accurate than C/A code receivers, but require more involved post-processing and stricter data collection requirements. Carrier phase receivers (survey grade) require a clear view to the satellites in order to maintain a constant lock with at least 4 satellites, while C/A code receivers (mapping grade) do not need to maintain a constant lock with the satellites to calculate positions. This makes a C/A code receiver imperative to gathering data in adverse conditions (for example, under trees). Although it is more difficult to gather carrier code data than solely pseudo-random code, accuracy is increased from 3-5 meter accuracy to sub-meter accuracy.

3.5.6.2. Sources of Error. GPS errors are combination of noise, bias and blunders.

Noise errors are the combined effect of PRN code noise (around 1 m.) and noise within the receiver noise.

Bias errors result from Selective Availability (SA) and other factors but SA is no longer an issue since May 2, 2000 5:05 am it was turned off. SA is an artificial falsification of the time in the L1 signal transmitted by the satellite. For civil GPS receivers that leads to a less accurate position determination (fluctuation of about 50 m during a few minutes). Other bias errors are: SV clock errors, ephemeris data errors, tropospheric delays, unmodeled ionosphere delays, reflected signal (multipath).

Blunders which can result in errors of hundreds of kilometers are: Control segment mistakes, user mistakes, receiver error from software or hardware (Sources of Errors in GPS, 2005, Kowoma GPS System Explained).

Table 3.2. GPS sources of error

Error Source	Standard GPS (m)	Differential GPS (m)
Satellite Clocks	1.5	0.0
Orbit Errors	2.5	0.0
Ionospheric effects	5.0	0.4
Tropospheric Effects	0.5	0.2
Receiver Noise	0.3	0.3
Multipath	0.6	0.6
Calculation-Rounding Errors	1.0	1.0
Selective Availability (not active now)	30.0	0.0
User Equivalent Range Errors	±31.4 (SA on) ±9.4 (SA off)	±0.9

3.5.6.3. Kinematic GPS. Various methods used to collect high precision GPS data. The particular method used depends on several factors, including survey objectives, desired precision, available equipment, and field logistics. Higher precision typically requires a more rigorous field methodology and longer occupation times. The following table shows the features of the most common GPS survey methods (Unavco Consortium, 2005):

Table 3.3. GPS survey methods

Survey Style	Accuracy (cm)	Occupation Time	Typical Applications
Continuous	0.0-0.5	Months or more	Crustal deformation, geophysics, reference stations
Static	0.5-5.0	Hours to Days	Crustal deformation, geodetic control, very long baseline surveys, geophysics
Rapid Static	1.0-5.0	Minutes	Short baseline surveys, glaciology
Kinematic	1.0-5.0	Seconds	Short baselines, closely spaced points, vehicle positioning, feature surveys, GIS and mapping
Code Differential	50-300	Seconds	Coarse GIS, mapping, positioning
Point Positioning	100-500	Minutes to Hours	Rough positioning

Continuous stations are included for comparison. For campaign-style data collection they typically serve as pre-existing base stations.

Static surveys are the standard campaign data collection method for crustal deformation surveys, and typically involve occupying each point for several days to get the highest possible accuracy.

Rapid static surveys are static surveys with just enough survey time at each point to be able to resolve the carrier phase integer ambiguity. A rule of thumb is to collect data for a minimum of 10 minutes per point, and add one minute of occupation time per kilometer of baseline length over 10 km. For example, on an eight-kilometer baseline collect data at least 10 minutes and on a 28 km baseline collect data at least 28 minutes.

Kinematic surveys rely on continuous tracking to resolve the integer ambiguity. The receiver/antenna may be moving during the surveys, but continuous lock on the satellite signals must be maintained. Since the data processing software is able to both resolve the ambiguity and track the antenna motion, fixed-integer solutions are obtained nearly instantaneously.

Kinematic GPS provides the opportunity to capture data with a vertical accuracy of ±2-3 cm and horizontal positioning double the accuracy. A minimum of two GPS receivers, linked by radio, are required. One receiver acts as a base station, providing corrections, the other is a mobile station used for collection of data. If carrier phase tracking system is used to determine the coordinates of unknown points, the method is called as Kinematic GPS and if code phase tracking system is used, then it is called as Differential GPS (DGPS).

Code differential surveys rely only on the code data to determine a differential solution. Simultaneous data collection between the base and rover receiver is still required, but there is no requirement to maintain continuous lock on the carrier phase since the phase data are not used. As a result, this method is extremely robust, but relatively coarse. For sub-meter accuracy, a rule of thumb is to collect data for five minutes per point, and add one minute of occupation time per five kilometers of baseline length over 10 kilometers. For example, on an eight-kilometer baseline collect at least five minutes of data and on a 108-kilometer baseline collect at least 25 minutes of data.

Point positioning uses only data from a single receiver to determine its coordinates. The collected data are averaged, and longer occupations significantly increase the accuracy. This method is very coarse, but sometimes it is the only way to determine base station coordinates while in the field. Although these coordinates may be off by about a meter, it is close enough to allow the computation of precise baselines while at a remote field location. When better network accuracy is desired, the base coordinates must be re-computed when back from the field.

3.5.6.4. Differential GPS. Differential GPS works by taking out many of the man-made and natural errors in GPS. These errors come from many sources such as imperfect satellite clocks and orbits, the earth's atmosphere (the charged particles in the ionosphere and the water vapor in the troposphere), multipath error from reflected signals and particularly the Selective Availability error which the U.S. military introduces through the satellite clocks and orbital data

To compensate for these errors we need to first measure them. This is done using one or more (wide area) reference stations. These reference stations are located at points that have been very accurately surveyed. The reference station receives the same GPS signals as the roving receiver, but instead of working like a roving receiver, it calculates backwards. Instead of using the satellite's timing signals to calculate a position, it uses its known position to calculate timing. The base station knows where the satellites are supposed to be and can calculate a theoretical distance between them.

By dividing that theoretical distance to each satellite by the speed of light, a theoretical time (how long the signal should have taken) is generated. The differential solution is the difference between the theoretical time and the measured time. This time difference (from each of the satellites it sees) is then sent to the rover GPS units through a tower or satellite transmission to apply a real time correction or it is stored for a later post processed correction.

4. DEPTH MEASUREMENT TECHNIQUES

People are always been curious about the land beneath the sea. Early sailors wanted to know the depth particularly along coastlines and near harbors so that their ship would not run aground. In time, demands for new resources, transportation and communication needs have shifted humankind to the seas.

Scientists make bathymetry maps of the seas to learn the surface, structure and shape of the planet. Early scientists measured the depths with weight on a rope but it was limited to shallow water by the lengths of line carried on board. Scuba and submersibles are also limited because of pressure and visual effects. Vertical distance must be measured to define the topography of sea surface. Invention of the echosounder to detect the enemy submarines during the World War II was very important step for bathymetry. The echosounder is just sonar and sonar is acronym for “sound navigation and ranging” (Ferrari, 1997) [13].

Depth measurement techniques can be grouped into two as classical (manual) and modern depth measurement techniques.

4.1. Manual Depth Measurement Techniques

Manual methods are generally used where more efficient acoustic methods cannot provide adequate depth data or sufficient detail such as underwater engineering and construction applications (US Army Corps of Engineers, 2002) [14]. Beach and dune profile surveys, power plants, dams, river control structures subject to turbulence, detailed surveys of rock jetties and breakwaters and survey in areas where unconsolidated sediments are present. Manual depth measurement techniques are simply a variation of conventional topographic survey methods. However, unlike land-based topographic surveys, geophysical properties of bottom are not always visible or consistent.

The methods which can be read directly are hand lead lines, topographic level rods and sounding poles.

I. Topographic Level Rods can measure up to 6 m with ±(5-10 cm) accuracy,

II. Sounding Poles can measure up to 30 m with ±10 cm accuracy.

III. Hand Lead Lines can measure from 30 m to 2000 m with ±0.01xH accuracy, where H is 1 per cent of depth.

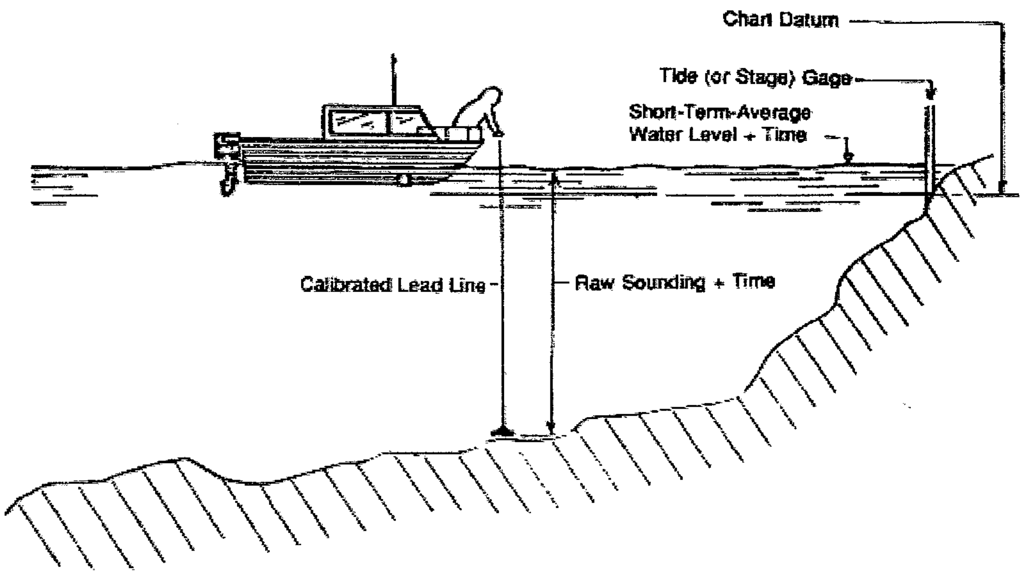

Figure 4.1. Lead line depth measurement

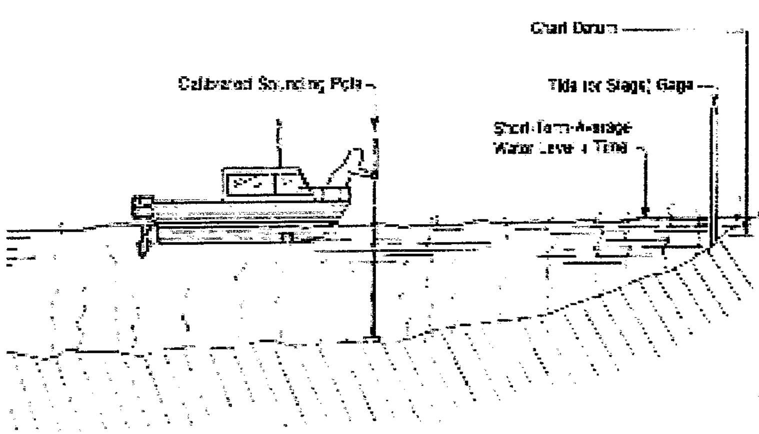

Figure 4.2. Sounding pole depth measurement

4.2. Modern Depth Measurement Techniques

The Global Position System (GPS) and advances in photography, laser, radar and remote sensing technologies have allowed the development of ground, air, and sea topographic and bathymetric surveying systems that can rapidly acquire data with vertical accuracy from 1 to 100 cm. Each surveying technique has its advantages with regard to accuracy, detail, aerial coverage, survey environment, availability, and cost. Modern techniques which are Remote Sensing, Photography, Laser and Acoustic explained below.

4.2.1. Remote Sensing

A simple definition of Remote Sensing is: Gathering data and information about the physical world by detecting and measuring radiation, particles, and fields associated with objects located beyond the immediate vicinity of the sensor devices (Short, 2006) [15]. Other definition can be made as: Remote Sensing is a technology for sampling electromagnetic radiation to acquire and interpret non-immediate geospatial data from which to extract information about features, objects, and classes on the Earth's land surface, oceans, and atmosphere (Örmeci, 1987) [16]. SPOT by France and LANDSAT by United States satellites are serving for remote sensing projects.

LANDSAT refers to a series of satellites put into orbit around the earth to collect environmental data about the earth's surface. The LANDSAT program was initiated by the U.S. Department of Interior and NASA on July 23, 1972, and was the first unmanned satellite designed solely to acquire earth resources data on a systematic, repetitive, multispectral basis. Over time, the sensors carried by the LANDSAT satellites have varied as technologies improved and certain types of data proved more useful than others.

Data collected from satellites are subject to atmospheric, geometric and radiometric distortion, for this reason they must be processed and modeled. Because measuring up to 20 m is possible by Remote Sensing, it is used at shallow seas. Advantages of this method are: Remote sensors detect over a broader area rather than a line that is it provides regional view and they can operate in all seasons, at night, in bad weather and in dangerous areas (Doğan and Alpar, 1994) [17].

4.2.2. Aerial Photography

Aerial photography is the taking of photographs from above with a camera mounted on an aircraft, balloon, rocket, kite or similar vehicle. It was first practiced by the French airman Nadar in 1858. Although aerial photos and maps show "bird eye" view of the earth, aerial photographs are not maps. Contrary to maps, aerial photographs display a high degree of radial distortion. That is, the topography is distorted, and until corrections are made for the distortion, measurements made from a photograph are not accurate. Nevertheless, aerial photographs are a powerful tool for studying the earth's environment.

Aerial photographs are separated from regular photos in at least three important ways (Crum, 1997):

I. Objects are portrayed from an overhead position
II. Infrared wavelengths are recorded very often
III. Photos are taken at scales most people are unfamiliar to see

Types of aerial photography are: Black and white, color and color infrared. Basic specifications which help us to identify objects on aerial photographs are listed below:

I. Tone (Hue or color): Tone refers to the relative brightness or color of elements on a photograph. It is, perhaps, the most basic of the interpretive elements because without tonal differences none of the other elements could be discerned
II. Size: The size of objects must be considered in the context of the scale of a photograph. The scale will help you determine if an object is a stock pond or lake.
III. Shape: Refers to the general outline of objects. Regular geometric shapes are usually indicators of human presence and use. Some objects can be identified almost solely on the basis of their shapes. For example, football fields, colorleaf highway interchanges, some government buildings.
IV. Texture: The impression of "smoothness" or "roughness" of image features is caused by the frequency of change of tone in photographs. It is produced by a set of features too small to identify individually. Grass, cement, and water generally appear smooth, while a forest canopy may appear rough.

V. Pattern: The patterns formed by objects in a photo can be diagnostic.

VI. Shadow: Shadows aid interpreters in determining the height of objects in aerial photographs. However, they also obscure objects lying within them.

VII. Site: Refers to topographic or geographic location. This characteristic of photographs is especially important in identifying vegetation types and landforms.

VIII. Association: Some objects are always found in association with other objects. The context of an object can provide insight into what it is. For instance, a nuclear power plant is not (generally) going to be found in the midst of single-family housing.

Although aerial photography has broader spectral sensitivity than the human eye and has better spatial resolution and geometric fidelity than many ground-based sensing methods, it is not favorable in deep water applications. Depth can be measured up to 3 m at unclear water while it is up to 25 m at clear water. Accuracy of method is ±40 cm. (Dinn) [18].

4.2.3. Airborne Laser – Light Detection and Ranging

Airborne Laser (Light Detection and Ranging - LIDAR) is a swath surveying technology for shallow coastal water which cannot be detected by multibeam acoustic system (Banic, 1999) [19]. The term lidar refers to the optical equivalent of radar and is often used in place of the more specific term, laser altimetry. Light detection and ranging technique accurately determines water depths by measuring the time of light of two laser pulses at different wavelengths: one travels through the air-water interface to the water bottom, while the second pulse is reflected from the water surface. An optical receiver on the aircraft detects the pulse reflections from both the bottom and the water surface. The water depth is determined by the elapsed time between these two reflections, after accounting for the system's operating geometry, propagation-induced biases and wave height and tide effects.

Basic principle is same as Remote Sensing but means of transportation is different - plane which flies at almost 300 m. LIDAR systems can provide uniform and dense data in extremely shallow water. It is a good complement to acoustical surveys, which are less effective in depths less than about 5 meters. The biggest limitation of LIDAR, as with other airborne techniques, is its dependency on water clarity. In clear waters it can be used to depths of over 50 meters but in turbid water it is only successful to depths of two to three times the visible depth. Accuracy for this method is ±20 cm.

4.3. Acoustics

Sound Navigation and Ranging (SONAR) system based on principle that a sound is sent into the water, it strikes an object or ground and reflected back. An instrument, called transducer, sends a sound pulse straight down into the water. The pulse moves down through the water and bounces off the seafloor. The transducer also picks up the reflected sound. Computers precisely measure the time it takes for the sound pulse to reach the bottom and return. The water depth is calculated by knowing how fast sound travels in the water. This method of seafloor mapping is called echosounding.

Sonar systems are classified as either active or passive. Active sonar uses a transducer to produce a constant stream of underwater sound pulses which reflect off of submerged objects and return to the transducer. Analysts then use the speed of sound underwater (a constant value of approximately 1500 meters per second) to calculate the exact distance of the submerged object from the transducer. Passive sonar only receives underwater sound pulses and then uses a computer database to match a specific sound pulse to identify the unknown sound pulse. Military primarily use passive sonar, whereas scientists use active sonar for oceanographic research.

4.3.1. Types of Echosounders

Echosounders transmit a single beam or multiple beams of sound simultaneously. Today several techniques are used to create maps of the seafloor for different purposes. There are many factors when deciding whether using either single-beam or multibeam bathymetry. Types of echosounder are explained below:

4.3.1.1. Single Beam Echosounder. Single-beam echosounders collect discrete data points along survey track lines. Sound pulses are sent from the transducer straight down into the water. The sound reflects off the seafloor and returns to the transducer. The time the sound takes to travel to the bottom and back is used to calculate the distance to the seafloor.

Water depth is estimated by using the speed of sound through the water (approximately 1,500 meters per second) and a simple calculation:

$$\text{Distance} = \text{speed x time}/2 \tag{4.1}$$

The product is divided by two because the measured time is the round-trip time (from the transducer to the seafloor and back to the transducer).

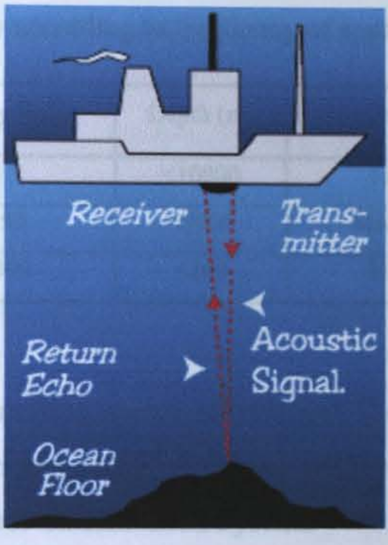

Figure 4.3. The way of sound

The sound pulses are sent out regularly as the ship moves along the surface, which produces a line showing the depth of the ocean beneath the ship. This continuous depth data are used to create bathymetry maps of the survey area.

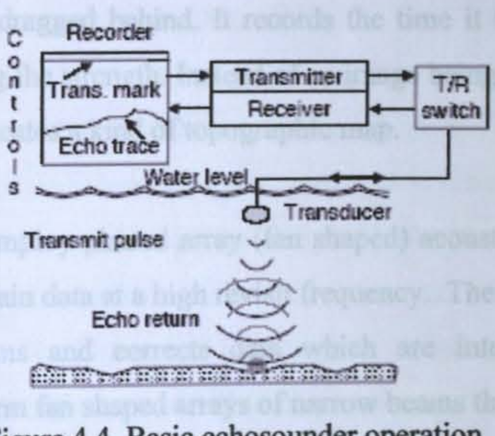

Figure 4.4. Basic echosounder operation

Echosounders can use different frequencies of sound to find out different things about the sea. Water depth is typically measured by echosounders that transmit sound at 12 kHz. Lower frequencies (3.5 kHz) can be used to look at the layers of sediments below the seafloor. Higher frequencies (200 kHz) can be used to identify fish and plankton that are in the water column. Important factor that affect the accuracy of depth measurement value is the frequency, that is, the higher the frequency, the more accurate the depth value.

Table 4.1. Accuracy according to frequency of sound wave for depth

Frequency (kHz)	Depth (m)	Accuracy (m)
1 - 15	<10000	Low
20 - 50	<5000	Medium
30 - 300	<300	High

Single-beam echosounders have several advantages: They are low cost and portable units that broad scale of users can deploy on small boats and ships. Also they can be interfaced with Acoustic Seafloor Classification System.

4.3.1.2. Multibeam Echosounder. Multibeam sonar technology uses multiple sound waves each from different transmitters on the haul of a ship to measure the depth of objects on the seafloor. Since multibeam systems rely on time measurements, the coverage area is dependent on the depth of the water, typically two to four times the water depth. Multibeam sonar also is a form of active sonar, but the sound emitting device is attached to a vessel, instead of being dragged behind. It records the time it takes for the echoes to return, rather than recording the strength. Instead of an image being created, this allows for depths to be measured. It creates a kind of topographic map.

Multibeam systems employ phased array (fan shaped) acoustic detection techniques that can record detailed terrain data at a high revisit frequency. The high revisit, number of times per second, confirms and corrects data which are interpolated by on-board computers. Transducers form fan shaped arrays of narrow beams that measure a swath that can map the sea floor, utilizing time of return to determine depth. Since the multibeam system generates so much data per second, it is capable of mapping 100 per cent of the bottom, providing highly detailed results. Additionally, some systems are advanced enough to locate objects underwater. Multibeam sonar coverage is limited by the depth of the water. The deeper the water, the narrower the fan must be to get higher resolution.

Some multibeam systems can simultaneously measure the strength of the reflected sound, which is known as backscatter. Hard acoustic returns indicate rock or gravel while softer returns indicate mud or silt. Backscatter information also allows for the accurate determination of material composition on the seafloor.

There are many factors to consider when deciding between using either single-beam or multibeam bathymetry. If the survey covers large and complex areas of the seafloor and requires complete bottom coverage, then multibeam systems may be the better option. Multibeam data will provide greater resolution and permit wider spacing of survey track lines. This could decrease the number of survey lines and reduce costly ship time. If lower resolution is acceptable, then single-beam bathymetry in conjunction with other technologies (such as side-scan sonar) may provide a lower cost alternative

4.3.1.3. Side Scan Sonar. Side Scan Sonar operates similar to other active sonar systems but provide a method for obtaining more detailed acoustical pictures of the sea. The scan transmits a fan shaped sound from a tow vehicle which is submerged from and attached to a surface vessel by a cable. The sound sweeps the seafloor from side to side. The width of the area covered by the scan normally covers a width of approximately 200 meters. The returned signal strength is measured, processed and recorded, creating an image where the shape of the seafloor and objects on it are discernable.

The side scan sonar system is used in creating images of the seafloor, such as a sunken ship. The strength of the return echoes is measured to create the image. An image created by using side scan sonar can be very detailed and looks like someone was shining a light on an object complete with shadows. Side scan systems are very accurate for imaging large areas of the seafloor. The higher the frequency of sound used by the system, the higher the resolution. For example, around 100 kHz systems provide wider coverage.

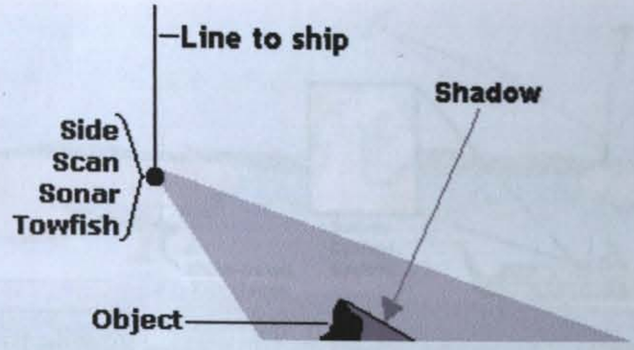

Figure 4.5. Sound way of side scan sonar

Side-scan sonar systems can identify different types of seafloor, such as mud, smooth sand, rippled sand, rock outcrops, and canyons. Dense objects such as rocks, coarse sand, and metal will reflect strong signals. Soft features such as silt, mud, or fine sediments absorb sonar energy and produce lighter acoustic returns.

Side-scan systems are very useful in turbid water conditions, but as with the other acoustic methods, some field verification using physical sampling or imagery is necessary. These systems do not produce any bathymetric information. Additionally, water depth must be at least 2 meters for sampling.

4.3.1.4. Split Beam Echosounder. Split beam echosounder or transducer is used for fish detecting activities. Hydroacoustic method has the capability of directly detecting the targets acoustic size and three dimensional position (Balk and Lindem, 2002). Tracking of individual fish targets using a split-beam echosounder is a common method for investigating fish behavior.

In general a split beam transducer is electrically divided into two orthogonal sets of paired receivers. An acoustic signal is transmitted and reflected from a fish and this echo encounters the two sets of receiving elements allowing the direction of arrival of an echo to be determined.

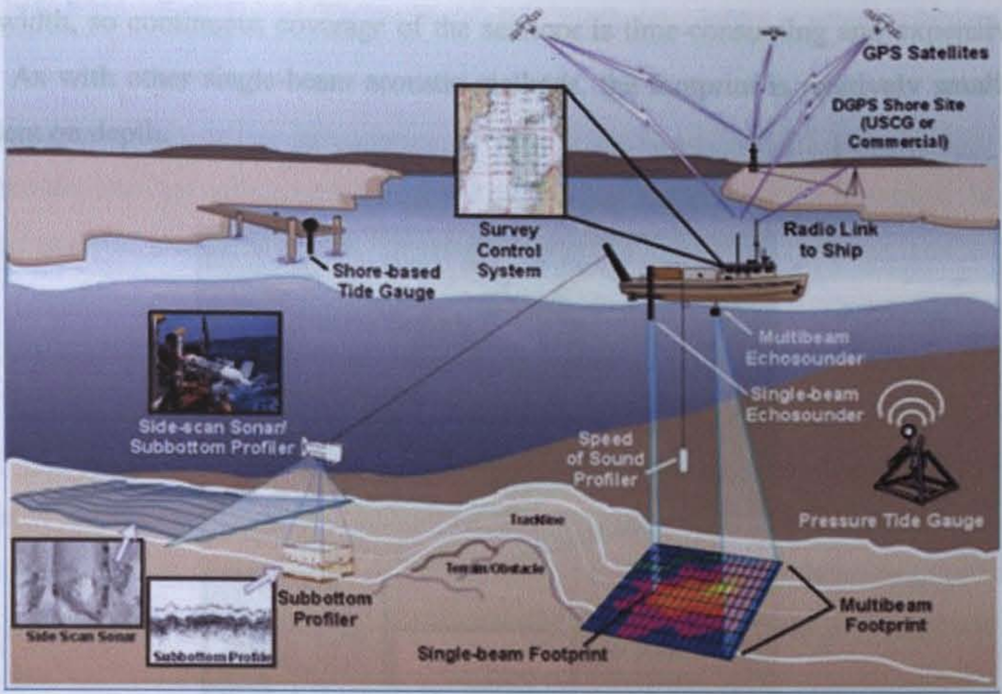

Figure 4.6. Acoustic seafloor characterization techniques

There are also several acoustic methods to characterize the seafloor. These acoustic systems use a technique that is similar to simple echosounders: Sub-bottom Profiling and Seafloor Classification System are two of most common used techniques.

Sub-bottom profiling systems are used to identify and characterize layers of sediment or rock under the seafloor. The technique used is similar to a simple echosounder. A transducer emits a sound pulse vertically downwards towards the seafloor, and a receiver records the return of the pulse once it has been reflected off the seafloor.

A sub-bottom profiler provides an acoustic profile of a narrow section of the sub-bottom directly beneath the path over which the device is towed. Sub-bottom profilers are impulse-type devices that transmit acoustic energy over a wide range of frequencies. Low frequency energy provides the greatest penetration while the higher frequencies and wide band widths provide higher resolution.

Sub-bottom profiling systems can be useful for characterizing benthic habitats, since they provide information about sub-surface sediment structure. No other acoustic techniques provide this type of information. Sub-bottom systems are limited by a narrow swath width, so continuous coverage of the seafloor is time-consuming and expensive to obtain. As with other single-beam acoustic methods, the footprint is relatively small and dependent on depth.

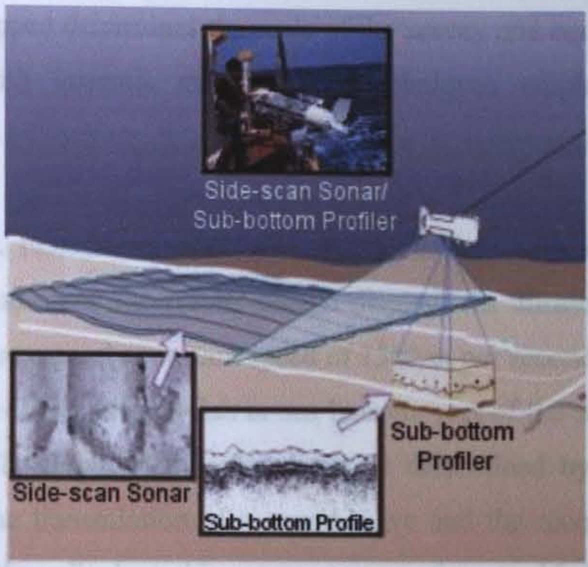

Figure 4.7. Sub-bottom profiler

Seafloor classification systems are used to classify features of the seafloor, such as vegetation or surface type. Some seafloor classification systems analyze the first return of a sound wave, while others analyze the first and second returns of a sound wave. They gather information about sediment properties for many engineering applications. In addition to sediment properties, geotechnical properties as attenuation, density, porosity, shear strength, compression and shear velocity, and mean grain size can be predict from the data recorded.

Advantages of system are: They are at low cost and portable so that can be used on boats with low power requirement. They also collect data quickly. On the other hand these systems are need on field calibration, so the data they produce are very difficult to interpret without physical sampling. Their swath width is narrow and acoustic footprint is relatively small and dependent on depth. Locating pipelines and other buried objects, industrial monitoring processes are some of the application areas.

4.3.2. Instruments of an Echosounder

There are many factors to consider when deciding which type of echosounder must be selected. Whether only depth measurement values are needed or complete bottom coverage must be mapped determines the scale of the survey and equipments. The surveys which conducted with acoustic measurement techniques employ echosounder and transducer.

4.3.2.1. Echosounder. Echosounders determine the distance between its transducer and underwater objects and show the results on the display. An ultrasonic wave transmitted through water travels at a nearly constant speed of 1500 m per second. When a sound wave strikes an underwater object such as fish or sea bottom, part of the sound is reflected back toward the source. The depth to the object can be determined by calculating the time difference between the transmission of a sound wave and the reception of the reflected sound. The sounder then displays this return as one of up to 16 different colors (color sounder) or a different level of gray scaling (monochrome sounder) depending on the strength of the returned signal.

A color echo sounder uses a different color for any one of up to 16 different signal strengths. This makes B returns show up as red and weaker colors as green or blue. Monochrome sounders use different levels of gray to show the different levels of signal strength. B returns such as a hard bottom show up as a very dark color and items such as debris in the water or concentrations of plankton appear as a cloudy gray.

There are two display types to choose from, Cathode Ray Tube (CRT) or Liquid Crystal Display (LCD). Each type has different advantages that need to be considered when choosing an echo sounder. A CRT is similar to a television screen. It has high contrast in normal to low light, allowing for bright and clear targets to be shown on the display. Bright sunlight will tend to make the CRT display fade. CRT echo sounders work best in an environment that is either covered or out of direct sunlight. With echo sounders, color units allow you to discriminate easier between small differences in signal returns.

Low and high frequency options, high resolution and accurate recording, time, velocity display other specifications needed. Additionally, they must be interfaced with computers and software solutions. The major difference between different types of echosounders is in the frequencies they use.

4.3.2.2. Transducer. The major function of the transducer is to convert electrical energy from the transmitter into sound/mechanical energy. The transducer then picks up the sound after it reflects off of the object. The transducer is one of the most important parts of an echosounder system. Transducer is mounted permanently in the bottom of the survey vessel, which then follows the track line generating soundings along the track.

Transducers can be classified according to their beam width, frequency and power rating. The sound radiates from the transducer in a cone, with about 50 per cent actually reaching to sea bottom. Beam width is determined by the frequency of the pulse and the size of the transducer. In general,

I. Lower frequencies produce a wider beam, and at a given frequency, a smaller transducer will produce a wider beam. Lower frequencies also penetrate deeper into the water, but have less resolution in depth. A typical low frequency transducer operates at 12 kHz.
II. Higher frequencies have greater resolution in depth, but less range, so the choice is a trade-off. Higher frequencies also require a smaller transducer. A typical high frequency transducer operates at 200 kHz.

4.3.3. Sound Velocity Measurement in Sea Water

Physical parameters must be known to determine the sound velocity in sea water. Density, salinity, pressure and temperature are the factors whixh affect the velocity of sound in water. Average density of sea water is 1.026 gr/cm^3, however it is also a function of density, salinity, pressure and temperature and changes. The lowest and the fast values of sound can be given as 1387 m/sn (in hot water)$< c <$ 1529 m/sn (in saline, cold water). Velocity of sound can be found by several ways.

4.3.3.1. <u>Sound Velocity by Equations</u>. There are many formulas to find the velocity of sound in water which are functions of salinity, density, pressure and temperature. One of these formulas is developed by Wilson.

$$c = V_0 + V(t) + V(p) + V(s) + V(stp) \tag{4.2}$$

where c: Velocity, V_0: Sound velocity at 0 °C, 3.5 per cent salinity, 750 mmHg, V(t): Polynomial of temperature °C, V(p): Polynomial of pressure kg/cm^2, V(s): Polynomial of salinity, V(stp): Polynomial of stp. For general use Wilson formula can be written (Doğan and Alpar, 1994).

$$c = 1449.2 + 4.623t - 0.0546t^2 + 1.391(s-35) \tag{4.3}$$

In warm seas Wilson formula may result in a few m/s miscalculations, so Kingsley and Frey defined another velocity formula for the oceans (Doğan and Alpar, 1994) [20]. In this formula Latitude L indicates that regional differences can affect the velocity of sound:

$$c = 1449.05 + 45.7t - 5.21t^2 + 0.23t^3 + (1.333 - 0.126t + 0.009t^2)(s-35) + (16.23 + 0.253t)(d(1-0.0026\cos L)) + (0.213 - 0.1t)(d(1-0.0026\cos L))^2 + (0.016 + 0.0002(s-35)t(d(1-0.0026\cos L)) \tag{4.4}$$

where t: Temperature °C/10, L: Latitude, d: Depth (km), s: Salinity (ppm)

4.3.3.2. <u>Sound Velocity by Bar Check Method</u>. Bar Check is a low cost, high accuracy hand held package designed to enable rapid checks of sound velocity in shallow water.
The principle of this method is sound reflecting and comparing. A plate, the depth of which is known, under the transducer reflects the sound back to transducer. Readings from transducer is compared with bar's level. The comparison must be repeated in several depths. If the difference between two readings are greater than precision value, then velocity of sonar is changed or measurements are corrected. The depth measurement by bar check method more than 30 m is not recommended because of the accuracy.

c^0: Sound velocity of instrument, c: Real sound velocity, d: Depth value from reflector, d_g: Depth value from instrument, then correction is found by;

$$t = 2d / c = 2d_g / c^0 \tag{4.5}$$

$$c = c^0 d / d_g \tag{4.6}$$

$$d = d_g c / c^0 \tag{4.7}$$

4.3.4. Depth Measurement Sources of Errors and Corrections

Acoustic method is the best way of depth measurement, however, some errors are inevitable to face with. Errors mainly can be classified as:

I. Errors from water (velocity of sound in water, sea surface changes…)
II. Instrument errors (vessel draft, heave, roll, pitch…)
III. User errors (installation error, misread, wrong measuring…)

Errors caused by water conditions and instrument errors can be removed from measurement values by applying corrections (Baş, 1998) [21]. Corrected depth value is determined by:

$$H_d = H' + a + dH_V + dH_e + dH_a + dH_H + dH_{PR} \tag{4.8}$$

Where H′: Measured depth value, a: Transducer depth correction, dH_V: Velocity correction, dH_e: Slope correction, dH_a: Instrument calibration correction, dH_H: Heave correction, dH_{PR}: Pitch and roll correction.

4.3.4.1. Transducer depth correction. Because some part of transducer is below the sea surface, it is added to depth soundings. Also value (a) can be added to the measurements by the computer automatically.

4.3.4.2. Velocity correction. Sound velocity depends on physical parameters of water and depth and if calibrated velocity value is different from real velocity value, then correction must be added to depth measurement values.

$$dH_V = H' (V_{ort}-V_o)/V_o \quad (4.9)$$

where V_{ort}: Average velocity for working area, V_o: Calibrated velocity value.

To enter the velocity of working area water to echosounder is more practical instead of making correction above, if the velocity value of echosounder could be changed.

4.3.4.3. Slope Correction. Sound pulses travel through the shortest way to seafloor and back. Since beam go out from the transducer in a conical shape, depth values at sloped seafloors is affected.

$$dH_e = H' \sin(\alpha_e/2) (\tan\beta_e-\tan\alpha_e/4) \quad (4.10)$$

where α_e: Transducer width, β_e: Slope of seafloor. If the slope of seafloor is smaller than $\alpha_e/4$, and transducer angle is smaller than 2°, then slope correction can be neglected.

4.3.4.4. Calibration correction. Disorder and inadequate calibration of echosounder cause this error. To identify the error value, measurements have to be made at sea which density and depth are known.

4.3.4.5. Heave Correction. Survey boat vertical boat movement resulting from wave motion can be a major contributor to errors in depth measurements. In the past manual or automatic smoothing the data only the practical way of correcting wave induced errors. New techniques do not give the opportunity to incorporate heave adjustment. The most widely used approach was to measure the survey boat's depth and position and correct the motion induced errors during post survey processing.

4.3.4.6. Pitch and Roll Correction. Pitch is the rotation about Y axes, Roll is the rotation about X axes. So many devices have been developed to remove these errors from measurements.

5. COORDINATE SYSTEMS

Coordinates reference some particular set of numbers for the size and shape of the Earth (Dana, 1995) [22]. There are many different coordinate systems, based on a variety of geodetic datums, units, projections, and reference systems in use. A datum is the mathematical model of the Earth we use to calculate the coordinates on any map, chart, or survey system. All the collected data must be carefully referenced by position on the Earth's surface.

GPS coordinates are commonly displayed as latitude and longitude which is an angular coordinate system. To get precise determination of the latitude and the longitude of points over working area, the shape of the Earth must be taken into account as an ellipsoid, not a sphere. The Earth's shape more closely approximates an ellipsoid (oblate spheroid): flattened at the poles and bulging at the Equator. Thus the Earth's shape, when cut through its polar axis, approximates an ellipse. A datum is also a standard representation of shape and offset for coordinates, which includes an ellipsoid and an origin.

Many different coordinate systems are used to coordinate the location. Some systems such as latitude and longitude are global systems that can be used to record position anywhere on the Earth's surface. Other systems are regional or local in coverage and intended to provide accurate positioning over smaller areas. The system of locational reference used in a particular will depend on the purpose of the project and how the positions of the source data have been recorded. It is sometimes the case that the data needed for a particular GIS project will be recorded in two or more of these reference systems. Combining the information of these sources will require that positions be carefully converted, transformed, or projected from one system to another

5.1 Basic Coordinate Systems

Basic coordinate systems represent points in two-dimensional or three-dimensional space. These systems used in analytic geometry are referred to as Cartesian Systems. Similar systems based on angles from baselines are often referred to as polar systems. Two-dimensional coordinate systems are defined with respect to a single plane while three-dimensional systems are defined with respect to two orthogonal planes.

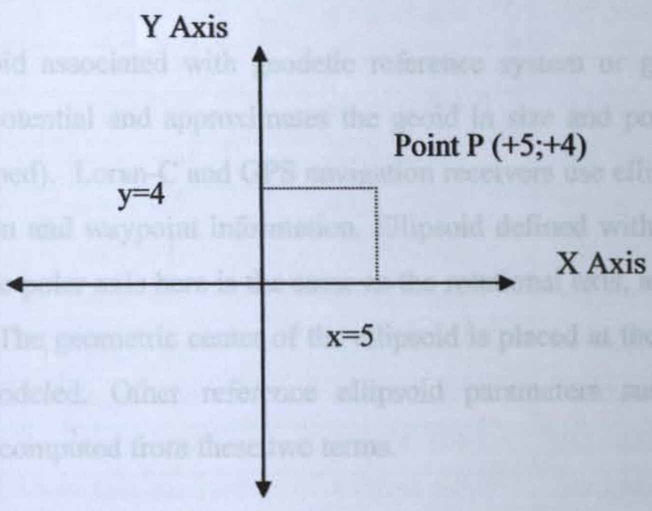

Figure 5.1. Cartesian coordinates in a plane

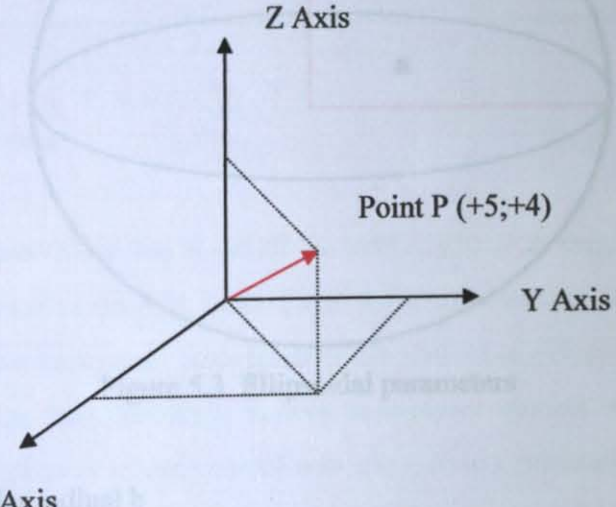

Figure 5.2. Three-dimensional cartesian coordinates

5.1 Basic Coordinate Systems

Basic coordinate systems represent points in two-dimensional or three-dimensional space. These systems used in analytic geometry are referred to as Cartesian Systems. Similar systems based on angles from baselines are often referred to as polar systems. Two-dimensional coordinate systems are defined with respect to a single plane while three-dimensional systems are defined with respect to two orthogonal planes.

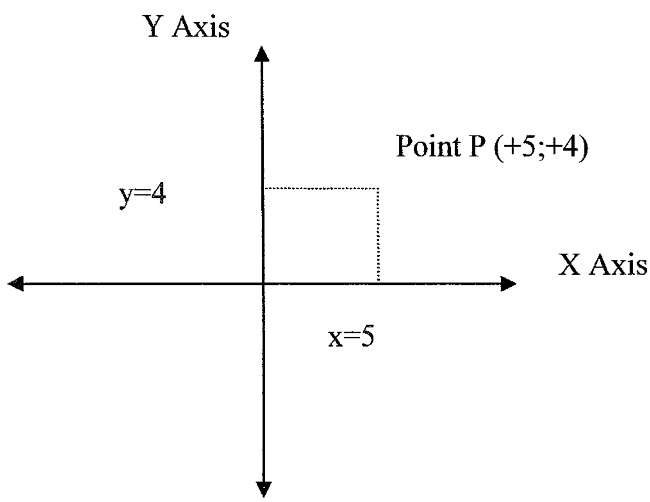

Figure 5.1. Cartesian coordinates in a plane

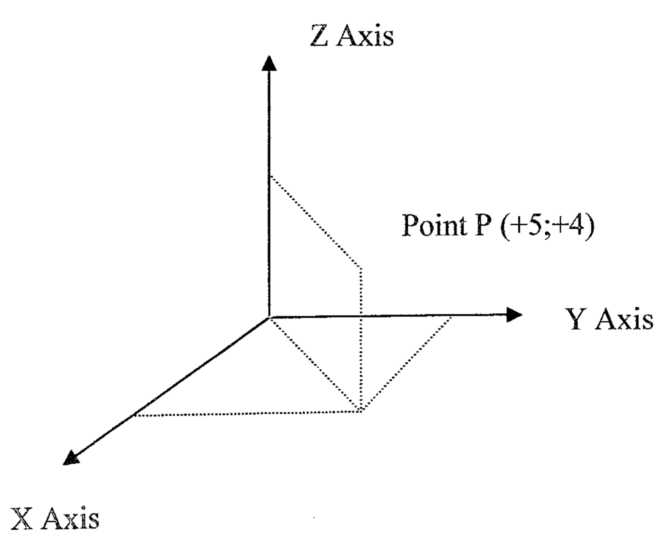

Figure 5.2. Three-dimensional cartesian coordinates

5.2. Earth-Based Locational Reference System

Map projections portray the nearly spherical earth in a two dimensional representation. Earth based reference systems are based on various models for the size and the shape of the earth. Although earth's shape represented in many systems by a sphere, precise positioning reference systems are based on an ellipsoidal earth and gravity models.

5.2.1. Reference Ellipsoid

An ellipsoid associated with geodetic reference system or geodetic datum whose surface is equipotential and approximates the geoid in size and position (literally, geoid mean Earth-shaped). Loran-C and GPS navigation receivers use ellipsoidal earth model to compute position and waypoint information. Ellipsoid defined with equatorial radius and polar radius. The polar axis here is the same as the rotational axis, and is not the magnetic or orbital pole. The geometric center of the ellipsoid is placed at the center of mass of the body being modeled. Other reference ellipsoid parameters such as flattening and eccentricity are computed from these two terms.

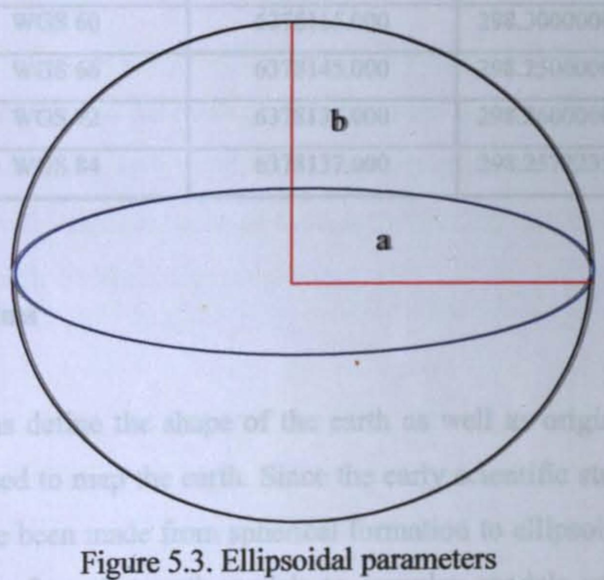

Figure 5.3. Ellipsoidal parameters

Semi minor axis (polar radius) b

Semi major axis (equatorial radius) a

Flattening f = (a-b)/a

First eccentricity squared $e^2=2f-f^2$

Table 5.1. Selected reference ellipsoids

Ellipse	Semi-Major axis (m)	1/Flattening
Airy 1830	6377563.396	299.32496460
Bessel 1841	6377397.155	299.15281280
Clarke 1866	6378206.400	294.97869820
Clarke 1880	6378249.145	293.46500000
ED 50	6378388.000	297.00000000
Everest 1830	6377276.345	300.80170000
Fischer 1960	6378166.000	298.30000000
Fischer 1968	6378150.000	298.30000000
GRS 1967	6378160.000	298.247167427
GRS 1975	6378140.000	298.25700000
GRS 1980	6378137.000	298.257222101
Hough 1956	6378270.000	297.000000000
International	6378388.000	297.000000000
Krassovsky 1940	6378245.000	298.300000000
South American 1969	6378160.000	298.250000000
WGS 60	6378165.000	298.300000000
WGS 66	6378145.000	298.250000000
WGS 72	6378135.000	298.260000000
WGS 84	6378137.000	298.257223563

5.2.2. Geodetic Datums

Geodetic Datums define the shape of the earth as well as origin and orientation of coordinate systems used to map the earth. Since the early scientific studies of the earth so many description have been made from spherical formation to ellipsoidal models. Modern geodetic datums range from flat-earth models to complex models used for international applications. These complex models describe the size, shape, orientation, gravity field and angular velocity of the earth.

Datums used as the basis for coordinate systems in geographic information system, precise positioning system and navigation may differ from nation to nation. Linking geodetic coordinates to the wrong datum can result in position errors for hundreds of meters.

The earth has irregular and constantly changing surface which are used in navigation, surveying and mapping.

Figure 5.4. Earth surfaces

Topographical surface of the earth is the actual surface of the land and sea at some moment in time and sea level is the average surface of the oceans. Gravity models describe in detail the variations in the gravity field. Geoid models attempt to represent the surface of the entire earth over both land and ocean as though the surface resulted from gravity alone. Reference systems can be divided into two groups

5.3. Global Coordinate Systems

5.3.1. Latitude, Longitude, Height

The most commonly used coordinate system is Latitude, Longitude and Height. The Prime Meridian and the Equator are the reference planes used to define latitude and longitude.

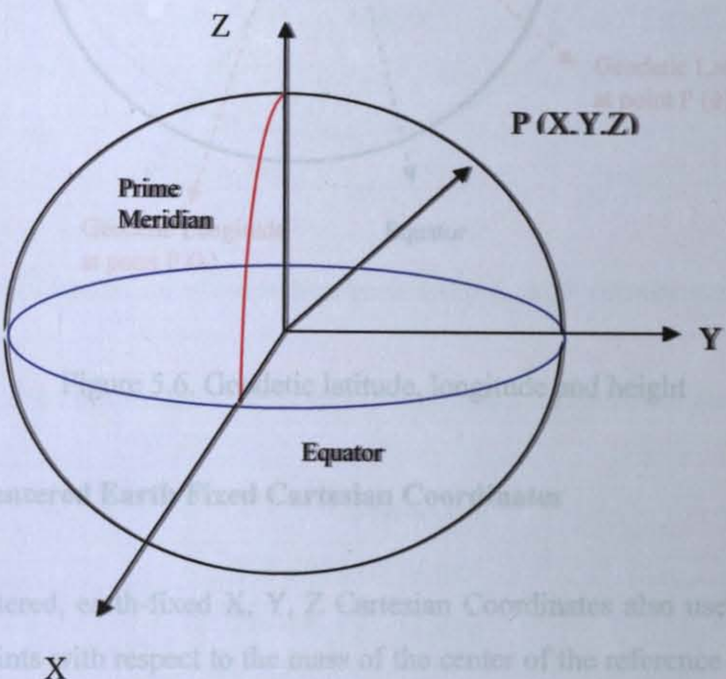

Figure 5.5. Equator and prime meridian

The geodetic latitude of a point is the angle from the equatorial plane to the vertical direction of a line normal to the reference ellipsoid. The geodetic longitude of a point is the angle between a reference plane and a plane passing through the point, both planes being perpendicular to the equatorial plane. The geodetic height at a point is the distance from the reference ellipsoid to the point in a direction normal to the ellipsoid.

GPS coordinates are commonly displayed as latitude, longitude and height, that is angular coordinate system. Degrees of latitude and longitude measure the angle between location and the reference line, namely the Equator and Greenwich England.

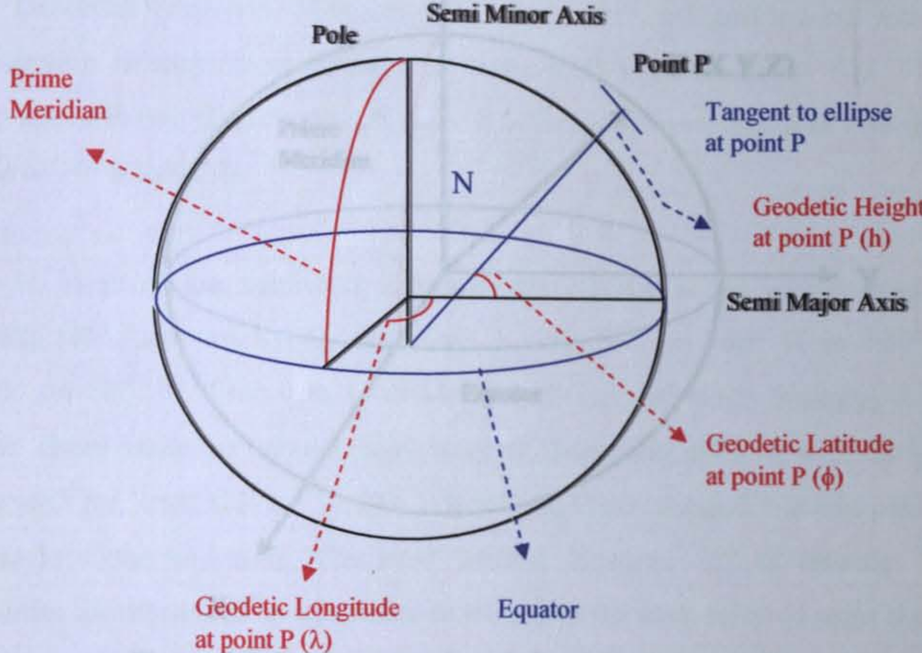

Figure 5.6. Geodetic latitude, longitude and height

5.3.2. Earth Centered Earth Fixed Cartesian Coordinates

Earth centered, earth-fixed X, Y, Z Cartesian Coordinates also used to define three dimensional points with respect to the mass of the center of the reference ellipsoid. The Z-axis points toward the North Pole, the X-axis is defined by the intersection of the plane define by the prime meridian and the equatorial plane and the Y-axis completes a right handed orthogonal system by a plane 90 degrees east of the X-axis and its intersection with the equator.

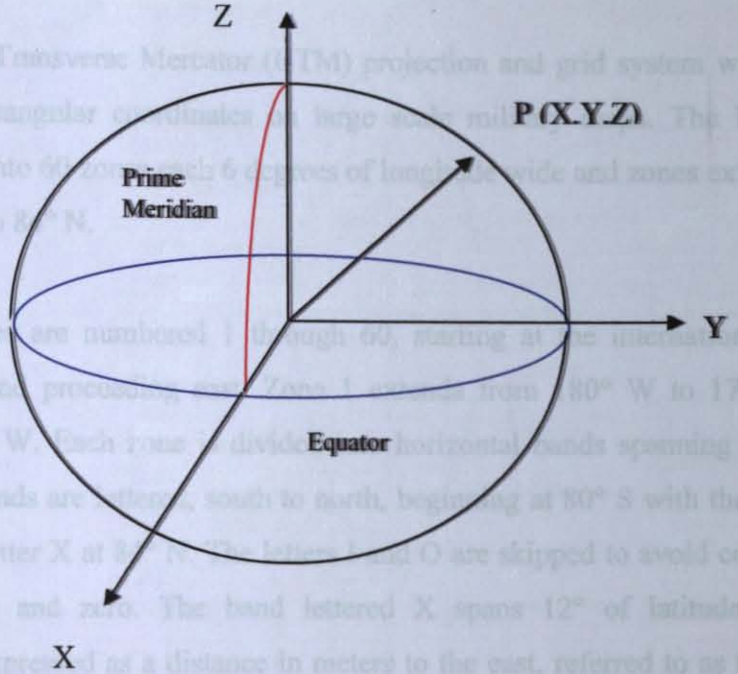

Figure 5.7. Earth centered earth fixed X, Y, Z coordinates

The conversion from ellipsoidal coordinates to cartesian coordinates is given by:

$$X = (N+h) \cos\phi \cos\lambda \quad (5.1)$$

$$Y = (N+h) \cos\phi \sin\lambda \quad (5.2)$$

$$Z = [(1-e^2) + h] \sin\phi \quad (5.3)$$

$$e^2 = (a^2-b^2)/a^2 \quad (5.4)$$

$$N = a^2 / \sqrt{(a^2 \cos\phi + b^2 \sin\phi)} \quad (5.5)$$

Where h: Altitude, λ: Latitude, φ: Longitude, e: First eccentricity, N: Radius of curvature in the prime vertical.

The conversion from cartesian coordinates to ellipsoidal coordinates is given by:

$$\lambda = \arctan (Y/X) \quad (5.6)$$

$$\phi = \arctan [(Z/\sqrt{[}\ (X^2 + Y^2)\ [1 - e^2 N / (N + h)]] \quad (5.7)$$

$$h = \sqrt{(X^2 + Y^2)} / \cos \phi - N \quad (5.8)$$

5.3.3. Universal Transverse Mercator

Universal Transverse Mercator (UTM) projection and grid system was developed for designing rectangular coordinates on large scale military maps. The UTM system divides the earth into 60 zones each 6 degrees of longitude wide and zones extend from the latitude of 80° S to 84° N.

UTM zones are numbered 1 through 60, starting at the international date line, longitude 180°, and proceeding east. Zone 1 extends from 180° W to 174° W and is centered on 177° W. Each zone is divided into horizontal bands spanning 8 degrees of latitude. These bands are lettered, south to north, beginning at 80° S with the letter C and ending with the letter X at 84° N. The letters I and O are skipped to avoid confusion with the numbers one and zero. The band lettered X spans 12° of latitude. UTM grid coordinates are expressed as a distance in meters to the east, referred to as the "easting", and a distance in meters to the north, referred to as the "northing".

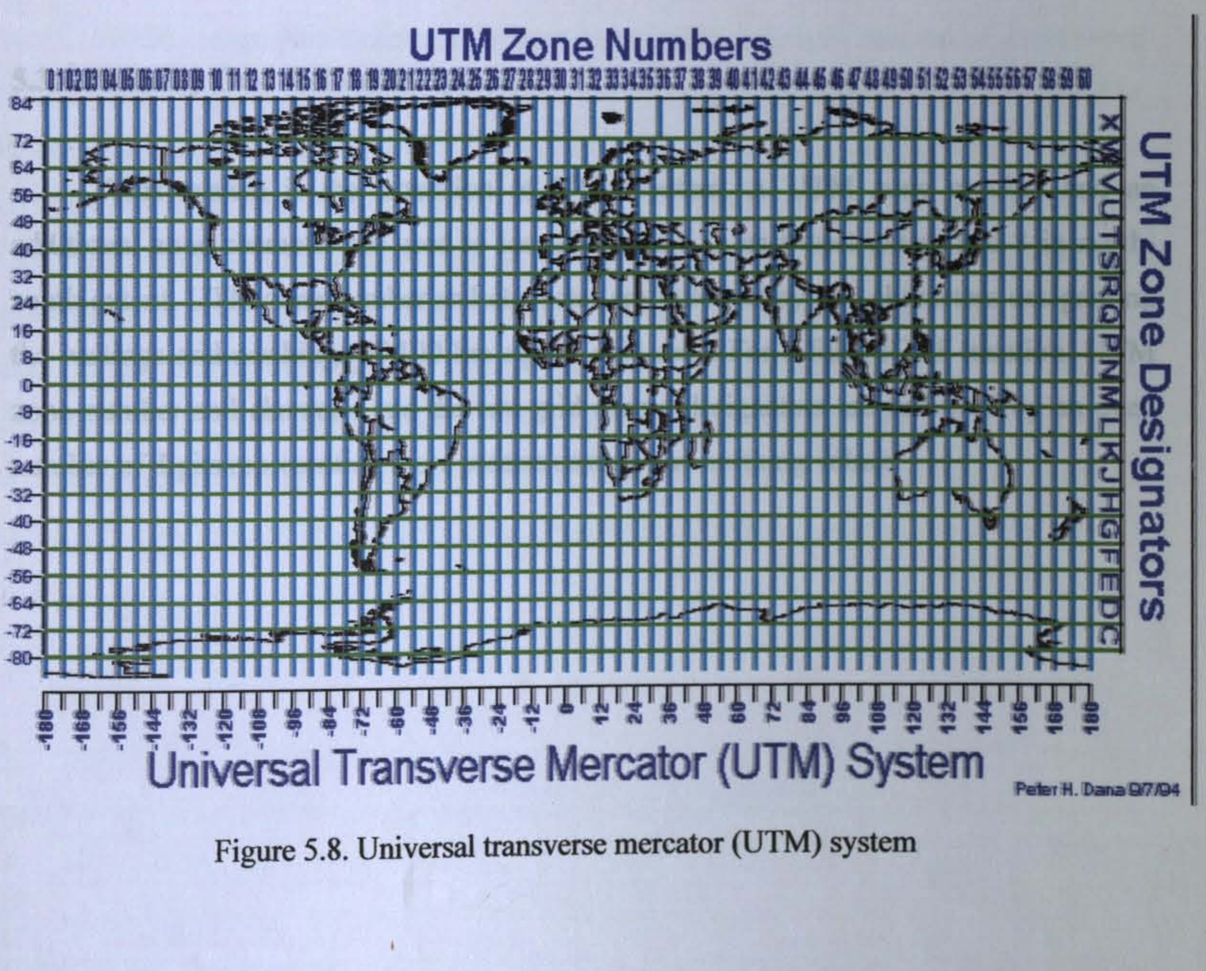

Figure 5.8. Universal transverse mercator (UTM) system

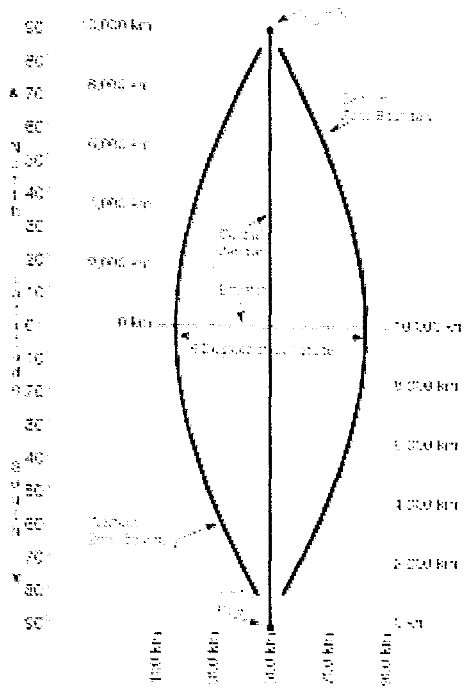

Figure 5.9. UTM display

5.3.4. Military Grid Reference System

This system is the extension of UTM system. A UTM zone number and an additional zone character are used to identify areas 6 in east-west extent and 8 in north-south extent. UTM zone number and character are followed by two characters designating the eastings and northings of 100 km square grid cells. For a full MGRS location, UTM zone number and character and the two grid square designators are followed by an even number of digits representing more precise easting and northing values.

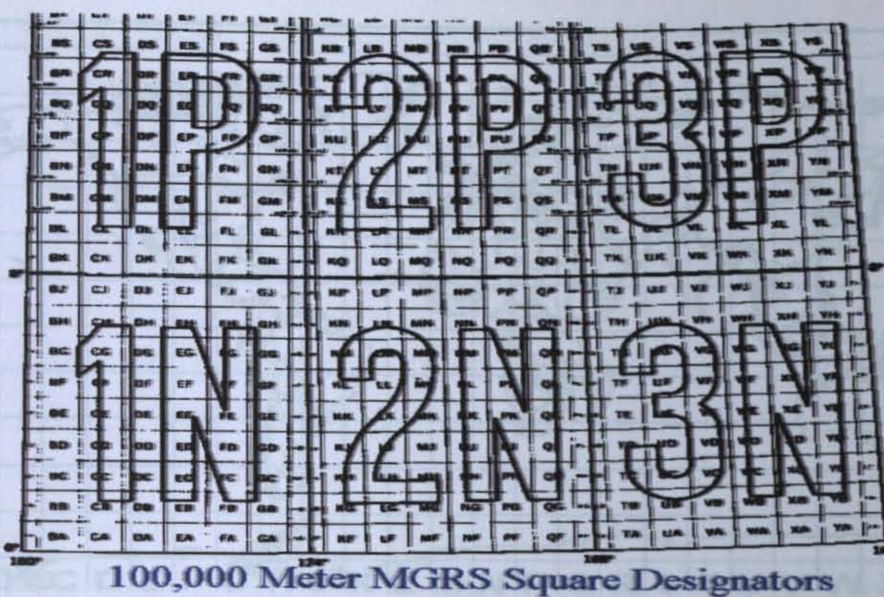

Figure 5.10. Military grid reference system (MGRS)

5.3.5. World Geographic Reference System

World Geographic Reference System is a simple and rapid method of expressing latitude and longitude. The GEOREF system enables any general position in the world to be located and is most valuable for use over large distances (primarily long-range air operations) or at great speeds. For this reason, it is used for aircraft navigation. The GEOREF system divides the Earth's surface into divisions and subdivisions. Its coordinates are read to the right and up. This system divides the world into 15° by 15° quadrangles. Beginning at the 180° meridian and proceeding eastward through 360° of arc, there are 24 15° longitudinal zones. These zones are lettered A through Z, omitting I and O. Beginning at the South Pole and proceeding northward through 180° of arc, there are 12 latitudinal zones of 15° each. These zones are lettered A through M, omitting I.

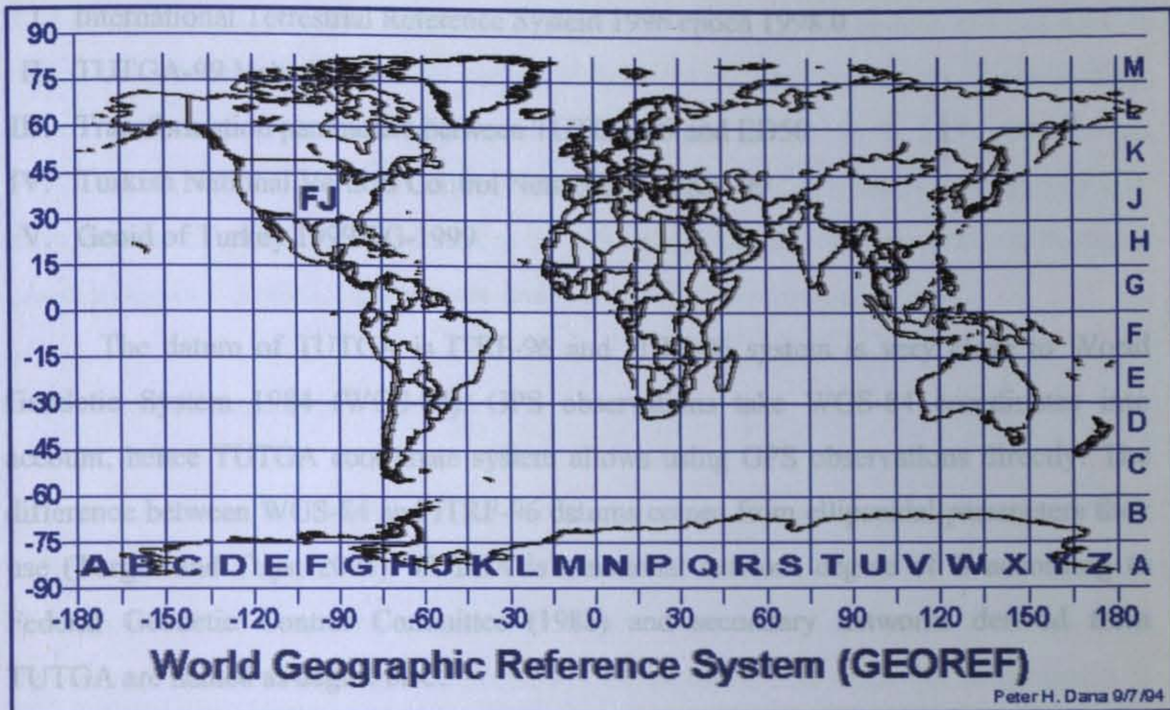

Figure 5.11. World geographic reference system

5.4. Regional Systems

5.4.1. Turkish National Fundamental GPS Network

The use of GPS in large scale map production encountered surveyors a need for a new coordinate system for meeting the expectations that modern national networks are supposed to satisfy. This coordinate system is used as a fundamental geodetic network for mapping.

Turkey General Command of Mapping (GCM) and The General Directorate of Land Registry and Cadastre (TKGM) decided to conduct a study to establish such a network in 1996 and after 3 years, Turkish National Fundamental GPS Network (TUTGA) has been defined. TUTGA is at International Terrestrial Reference Frame, accuracy of ±(1-3)cm, 3D (X,Y,Z) coordinate system. Coordinate changes according to time are (V_x,V_y,V_z) and height is H, geoid height is N, 594 point network. TUTGA depends on five criterias:

I. International Terrestrial Reference System 1996 epoch 1998.0
II. TUTGA-99 Velocity Area
III. Transformation parameters between TUTGA-99 and ED50
IV. Turkish National Vertical Control Network TUDKA-99
V. Geoid of Turkey 1999 TG-1999

The datum of TUTGA is ITRF-96 and ITRF-96 system is very close to World Geodetic System 1984 (WGS-84). GPS observations take WGS-84 coordinates into account, hence TUTGA coordinate system allows using GPS observations directly. The difference between WGS-84 and ITRF-96 datums comes from ellipsoidal parameters they use (Turgut and Tuşat 2005). TUTGA is a national network degree of B according to Federal Geodetic Control Committee (1988) and secondary networks derived from TUTGA are named as degree of C.

In order to determine the heights according to geoid, ortometric height system has to be defined, so in 1991 Gravimetric Geoid of Turkey-1991 (TG-91), in 1999 Geoid of Turkey (TG-99) and in 1999 again Updated Geoid of Turkey 1999 (TG-99A) have been defined (Gürdal and Ceylan, 2005) [23].

In addition to TUTGA, there is one more coordinate system used in Turkey, National Coordinate System, which is defined only by terrestrial survey. Because of not developed and updated for years, National Coordinate System is almost not valid. The datum of National Coordinate System is European Datum 1950 (ED-50).

5.4.2. International Terrestrial Reference Frame

Until 1984 the rotation of the earth was monitored using a rigid earth model from number of observatories undertaking latitude and time observations. In 1984, a new conventional terrestrial system was defined and adopted with the knowledge that a rigid earth model was no longer appropriate. With the advance of increased geodesy activities and extra terrestrial sources, geodetic and astronomic unions recommended that an international earth orientation service. So, monitoring earth rotation and International Terrestrial Reference Frame (ITRF) replaced from 1st January 1988. The origin of ITRF is at the center of the mass of the earth. The ITRF is based on the combination of sets of station coordinates of points on the surface of the earth and their crustal motion velocities, derived from observations of space-geodetic techniques VLBI, LLR, SLR, GPS (since 1991) and DORIS (since 1994). The strength of the ITRF is that it uses a well distributed, large number of global points to monitor the dynamic earth surface. This dynamic model is based on the best available global data, and it is stable at the centimeter level.

5.4.3. World Geodetic System 1984

The World Geodetic System 1984 is a geodetic reference system used by GPS. WGS-84 system is very closely aligned to ITRF and the origin of WGS-84 is earth's center of mass. All GPS receivers compute and store coordinates in terms of WGS-84, then transform to other datums when information is displayed. Although the local datum is selected for display, WGS-84 values are downloaded via their data cable to a computer. The reference ellipsoid used with WGS-84 is essentially the same as the Geodetic Reference System 1980 (GRS80) ellipsoid used with ITRF.

5.4.4. European Datum Coordinate System 1950

National Coordinate System, coordinates from GPS and TUTKA are at different datum and their reference ellipsoids are also different. National Coordinate System of Turkey accept two dimensional European Datum 1950 (ED50) as a reference. ED-50 composed of Hayford Ellipsoidal coordinates or Easting, Northing UTM coordinates which is calculated from Hayford Ellipsoidal Coordinates. On the other hand by linking GPS observations to TUTGA, (X,Y,Z) coordinates at ITRF and latitude, longitude and height according to GRS-80 ellipsoid can be calculated. ITRF coordinates must be known in order to transform GPS observations to ED-50 that is transformation parameters can be calculated.

Table 5.2. Geodetic base for Turkey

Reference System	Datum	Ellipsoid	Coordinate System	Projection
National System	ED-50	Hayford	$2B(\phi,\lambda)+H$	TM-UTM
TUTGA	ITRF-96	GRS-80	$3B(\phi,\lambda,h)+T$	TM-UTM
GPS	WGS-84	WGS-84	$3B(\phi,\lambda,h)$	TM-UTM

Table 5.3. Parameters of reference systems of Turkey

R.S.	a	b	e^2	1/f
GRS-80	6378137	6 356 752.3141	0.006 694 38002290	298.257222101
WGS-84	6378137	6 356 752.3142	0.006 694 379 99013	298.257223563
ITRF-96	6378137	6 356 752.3141	0.006 694 38002290	298.257222101
ED-50	6378388	6356911.946	0.00672267002	297.000000000

6. APPLICATION

The Bosphorus crossing railway project Marmaray is one of the most complex infrastructure project of the world. The Bosphorus will be crossed by a 1.4 km immersed tube tunnel between Sarayburnu on the European side and Salacak on the Asian side of Istanbul (Ünlütepe, 2006) [24]. The parts of the tunnel dimensions of which are 135m x 8.6m x 15.3m have been constructing in a dry dock in Tuzla area. (www.marmaray.com)

Figure 6.1. The Marmaray Project

The aim of the application is to measure the depths in the construction area in order to flatten the surface of the sea to lower the tubes. The responsible directorate for the implementation of the project D.L.H. has some technical and contractual requirements from each contractor to obey during project (Marmaray BC1 Project Employer' Requirements, Chapter 1). Setting out (1.8.1), topographic (1.8.3) and hydrological surveys (1.8.5) have been performed according to Employer's Requirements.

6.1. Survey Area

.

Project area is D.L.H. harbor, Tuzla, at Asian side of Istanbul, where immersed tube tunnel elements are constructed. D.L.H. which is General Directorate of Railways, Harbors and Airports Construction under the Ministry of Transportation is the employer of the Marmaray Project. Parts of the immersed tunnel will be lowered sea, which has been dredging and excavating, for the quality control after construction is completed Afterwards they will towed out and immersed into when their trench is prepared through the Bosphorus.

Figure 6.2. Project area in D.L.H. harbor

6.2. Topographic Surveying Activities

Construction activities need some topographical and bathymetric surveying procedures to draw maps for dredging and excavation activities in the harbor during construction of the immersed tunnels. Photogrammetric map of the region was supplied from Istanbul Metropolitan Municipality and preliminary designs have been organized on this map. There were three TUTGA network control points, one of them is inside the project area and only that point could be seen. Totally 14 control points have been installed, 13 of them were secondary control points. Coordinates of primary network point at 3 degrees of longitude wide system is given Table 6.1.

Table 6.1. Coordinates of primary control points

PN	Y	X	Z
43713	438295.974	4522579.729	3.918

Measurements were made by Trimble 3603 DR Total Station and completed in four days. Staff of the both topographic and bathymetric survey is listed below:

1 Civil Engineer

1 Geodesy an Photogrammetry Engineer

2 Topographers

1 Vessel Operator

Evaluations made by Eghas, Tgen, EMP software programmes. They were homogenized by Samkub software programme and edited by Microstation software programme. The system was 12.7498 degrees oriented but it was linked to vertical datum TUDKA, Turkish National Vertical Control Network using trigonometric leveling.

Table 6.2. Trimble 3603 DR total station technical specifications

Angle Measurement	3′
Distance: prism mode	Standard +/- (2 mm + 2 ppm) - Rapid +/- (3 mm + 2 ppm) - Tracking +/- (5 mm + 2 ppm)
Distance: reflex mode DR	Standard +/- (3 mm + 2 ppm) - Rapid +/- (5 mm + 2 ppm) - Tracking +/- (10 mm + 2 ppm)
Telescope magnification	30x
Field of view	1.2 degrees
Shortest focusing distance	5ft. / 1.5 m
Angle measurement Hz and V circles	Electronic incremental
Measuring Units	360° (DMS), 360° (DEG), 400 gon, 6400 mils
Vertical Reference System	zenith angle, elevation angle, vertical angle, slope in percent
Least display unit	1′
Prism range	prism: 10032 ft. 3 prisms: 16400 f
Long range mode	1 prism: 16400 ft. 3 prisms: 24800 ft
Prism mode measuring time	Standard mode 2′ - Rapid mode 1.8′ - Tracking 0.5′
Direct reflex measuring time	Standard mode 3′ - Rapid mode 2′ - Tracking 0.8′

Table 6.3. Coordinates of secondary control points

PN	Y	X	Z
1001	438367.194	4522579.729	6.148
1002	438460.852	4522653.100	3.270
1003	438446.193	4522763.823	1.766
1004	438383.179	4522704.628	1.720
1005	438331.078	4522664.679	1.435
1006	438226.808	4522587.188	3.644
1007	438155.127	4522658.195	3.686
1008	437998.575	4522846.308	3.802
1009	438303.581	4522749.553	3.615
1010	438390.267	4522848.211	1.530
1011	438263.828	4523011.376	1.415
1012	438058.853	4522994.753	1.462
K.1091	438089.382	4523057.256	1.444

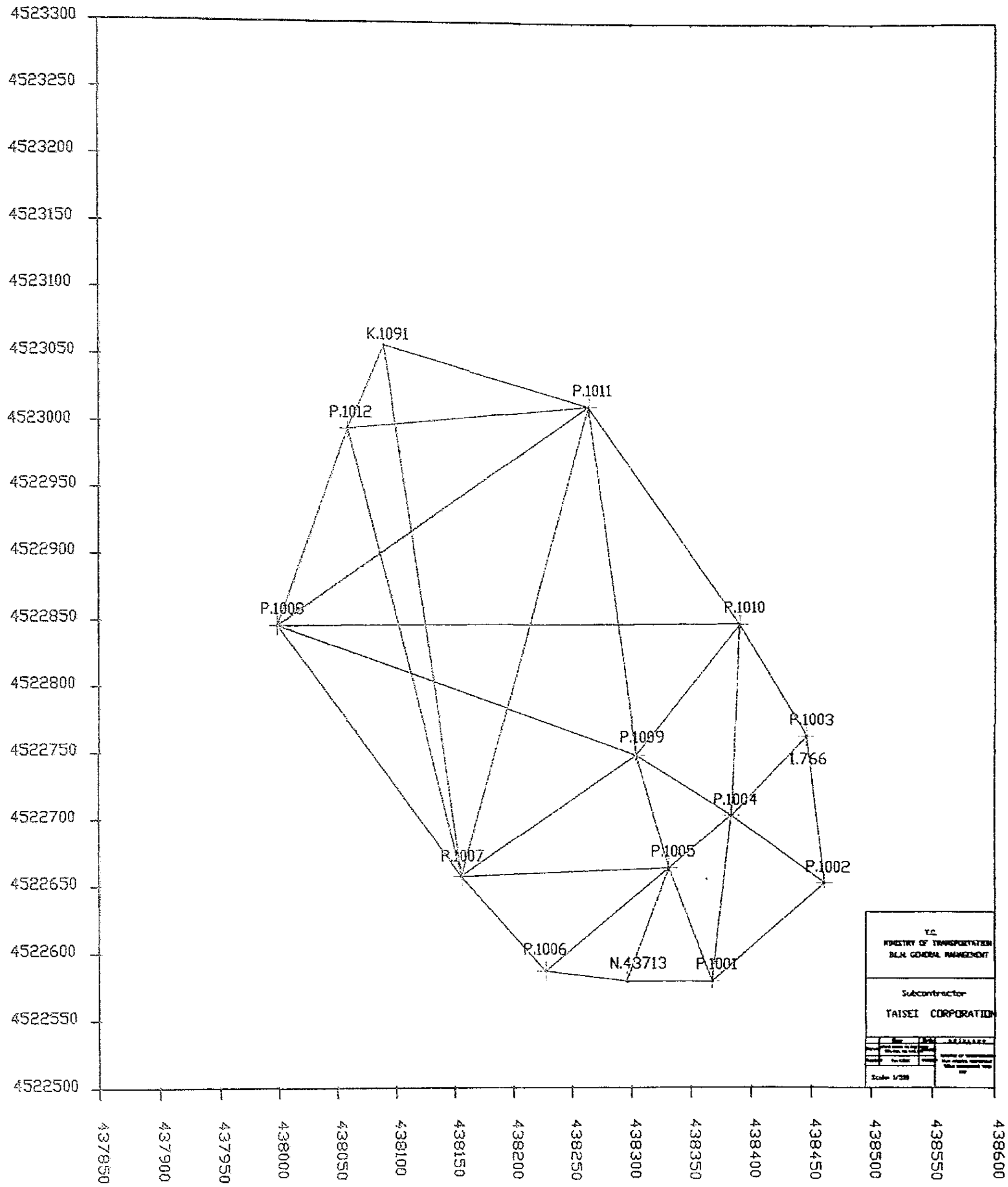

Figure 6.3. Primary and secondary control points of D.L.H. harbor

Detailed measurements in order to define the survey area were performed by Trimble 5503 DR Total Station and measured data of 1109 points evaluated for the map drawings (Table A.1).These map drawings would be a base for the proceeding bathymetric survey data.

Table 6.4. Trimble 5503 DR total station technical specifications

Angle Measurement Accuracy	3′
Standard angle reading	1′
Fast standard	1′
Tracking	2′
Arithmetic mean value	1′
Standard distance measurement accuracy	± (3mm+3ppm)
Fast standard	± (8mm+3ppm)
Tracking	± (10mm+3ppm)
Arithmetic mean value	± (3mm+3ppm)
Shortest possible range to prism	2m
Direct reflex	2m
Reflective foil	2m
Standard measuring time	3s
Fast standard	3s
Tracking	0.4s

GPS network measurements performed by Trimble 5700 RTK GPS System.

Table 6.5. Trimble 5700 RTK GPS system technical specifications

Frequency	Dual
Channels	24 channels
L1 Channels	Carrier phase, C/A code
L2 Channels	Carrier phase
Initialization time	±10s+0.5 x baseline km (up to 30 km)
Code DGPS horizontal accuracy	± (0.25m+1ppm)
Code DGPS vertical accuracy	± (0.5m+1ppm)
Static GPS horizontal accuracy	± (5mm+0.5ppm)
Static GPS vertical accuracy	± (5mm+1ppm)
RTK GPS horizontal accuracy	± (10mm+1ppm)
RTK GPS vertical accuracy	± (20mm+1ppm)

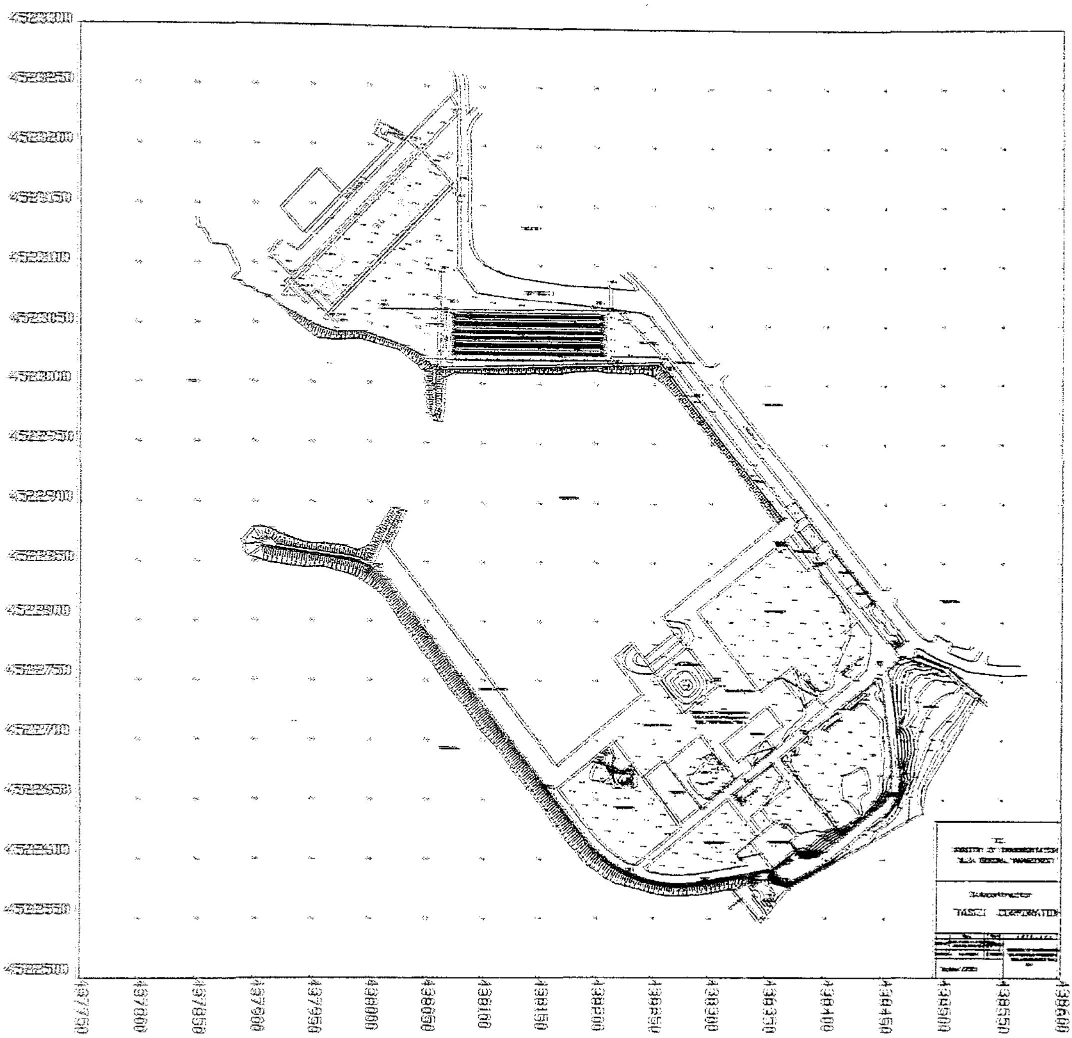

Figure 6.4. D.L.H. harbor map

6.3. Bathymetric Surveying Activities

Completing topographic survey and installation of points and calculation of coordinates proceed by bathymetric survey. Local tide gauge system installation, measuring the depths and positioning are the steps of bathymetric survey.

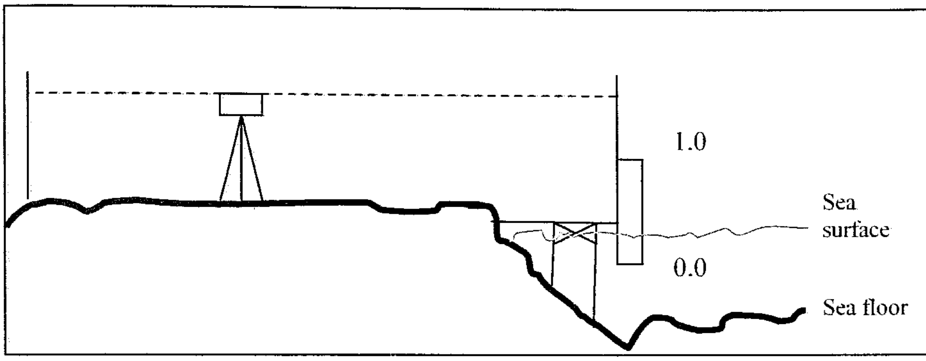

Figure 6.5. Tide gauge system

To link the depth values to a vertical datum, a mareograph station is needed. These stations are highly cost, complicated installation, so local, basic tide gauge system is easier way to measure the tide values. Topographic level rod has been installed to measure the sea level changes at survey area and height of zero point of rod has been found by geometric leveling. ±30 cm level changes have seen during the survey activities.

Providing accurate information on the water is very difficult because of the water movements. RTK GPS system which allows a very precise survey in real-time without the need for post processing has been used for positioning and bathymetric survey. Bathymetric surveys which executed nine times at the D.L.H. harbor where the immersed tunnel parts are produced. Equipment used for the surveys are listed below:

I. Trimble 5700 RTK GPS for base station
II. Trimble 5700 RTK GPS for station on the survey boat
III. Single Beam Raytheon DE719E Precision Survey Fathometer
IV. Notebook Computer and Hydropro Hydrographic Survey Software
V. Bar check
VI. Survey Boat

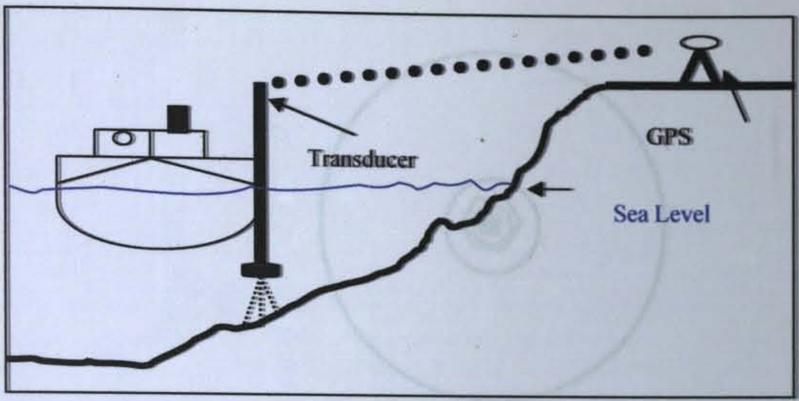

Figure 6.6. Bathymetric survey system

Marine surveys executed by Detek Offshore Technologies Ltd. Co. which supplied the technical equipment.

Table 6.6. Raytheon DE719E fathometer technical specifications

Depth Range	160m
Accuracy	0.5 per cent of indicated depth
Depth Resolution	0.1 unit (0.01m, less than 100m)
Frequency	200 kHz
Output Power	500 watt
Light weight	20 kg
Dimension	46cm H, 40cm W, 23cm D
Records	Depth, Navigation Fix Marks, Time
Displays	Sound Velocity, Tide, Draft
Transducer beam width	10° (Typical)
Transmit Sensitivity	170 (Typical)
Receive Sensitivity	-190 (Typical)
Pulse Power	500 watt

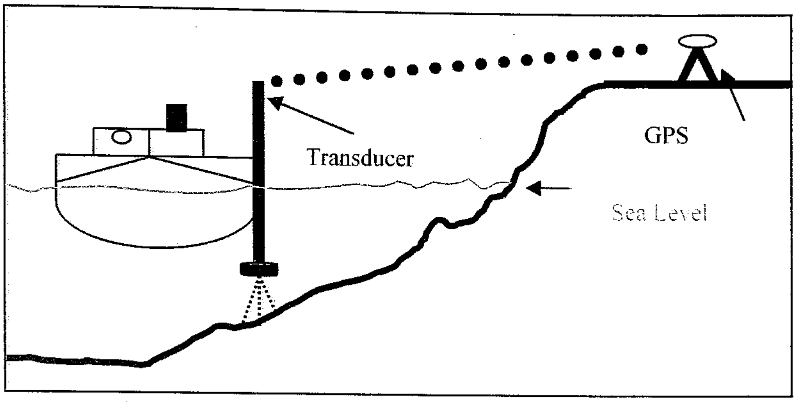

Figure 6.6. Bathymetric survey system

Marine surveys executed by Detek Offshore Technologies Ltd. Co. which supplied the technical equipment.

Table 6.6. Raytheon DE719E fathometer technical specifications

Depth Range	160m
Accuracy	0.5 per cent of indicated depth
Depth Resolution	0.1 unit (0.01m, less than 100m)
Frequency	200 kHz
Output Power	500 watt
Light weight	20 kg
Dimension	46cm H, 40cm W, 23cm D
Records	Depth, Navigation Fix Marks, Time
Displays	Sound Velocity, Tide, Draft
Transducer beam width	10° (Typical)
Transmit Sensitivity	170 (Typical)
Receive Sensitivity	-190 (Typical)
Pulse Power	500 watt

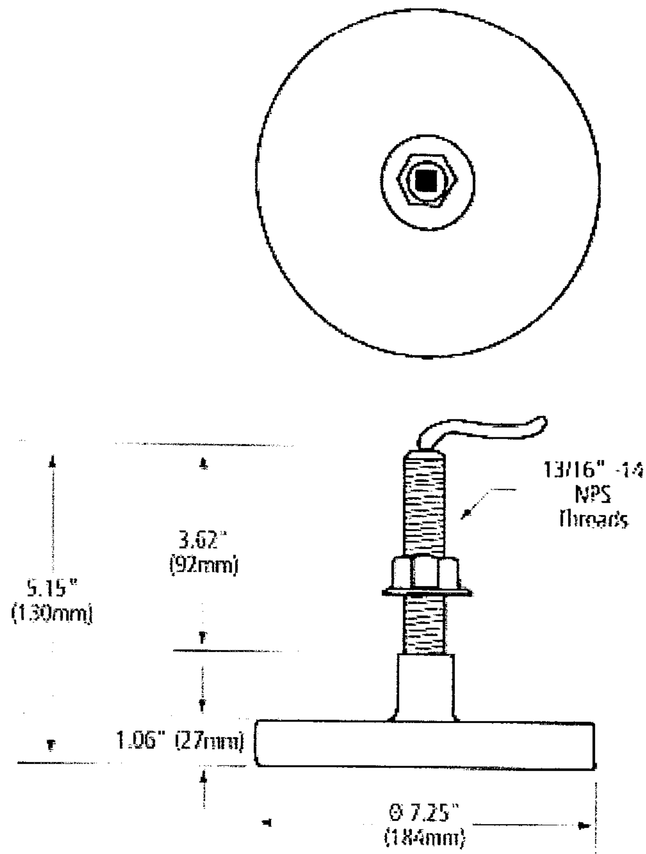

Figure 6.7. Dimensions of transducer's parts

The survey was conducted during the period from February to April 2006, an estimated 35.000m2 area. For this survey Trimble RTK GPS system was used to get navigational information. Tidal corrections were provided by a continuous-logging tide gauge. Sound velocity measurements were made before and during the survey for correction of the sonar data by bar check method. Survey lines were located to give 100% overlap between swaths running both north-south and east-west. The grids were vertical to the coast and distance between the grids was very close, 2m. Survey lines can be seen at figure 6.8.

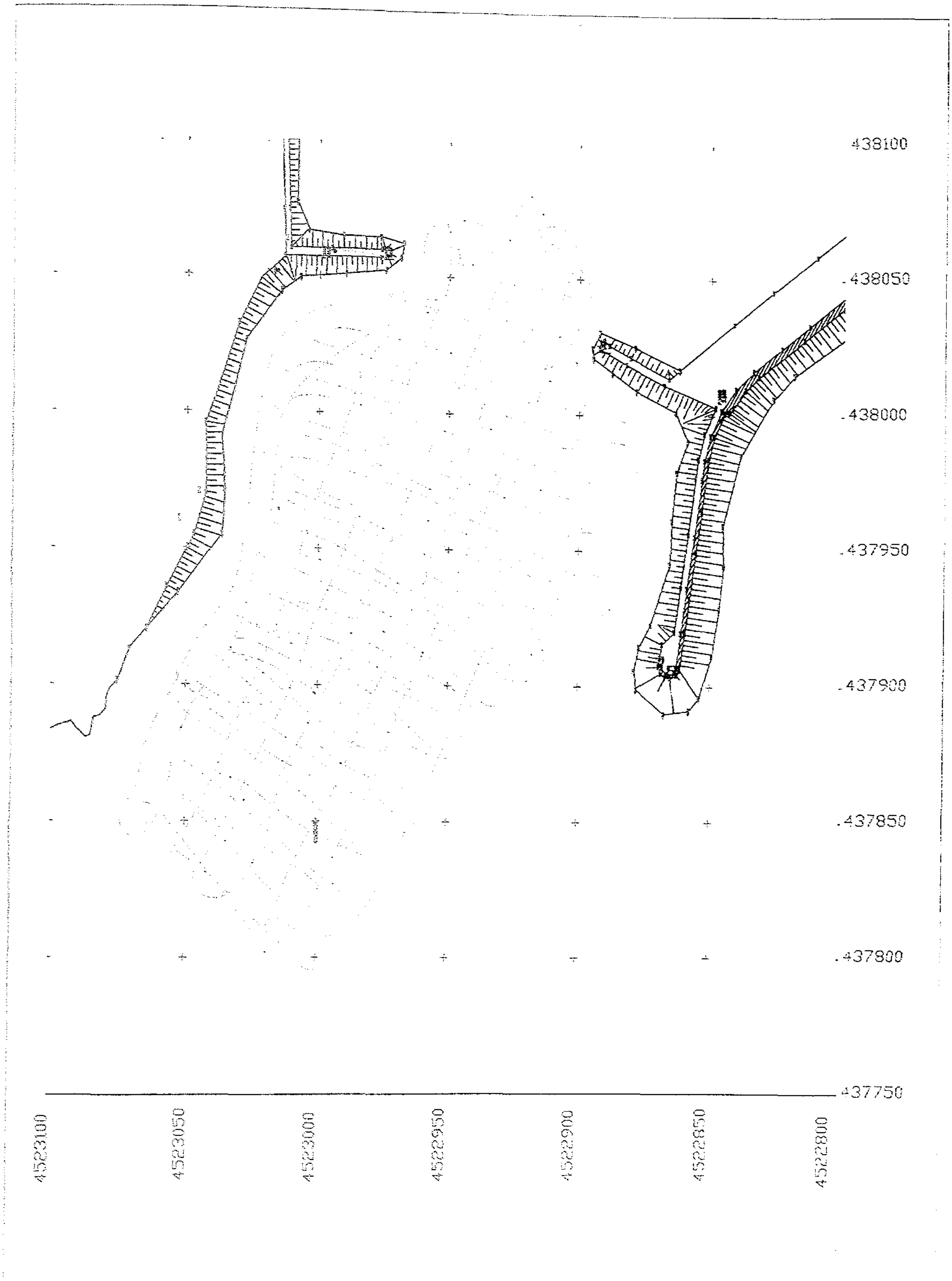

Figure 6.8. Bathymetric survey lines

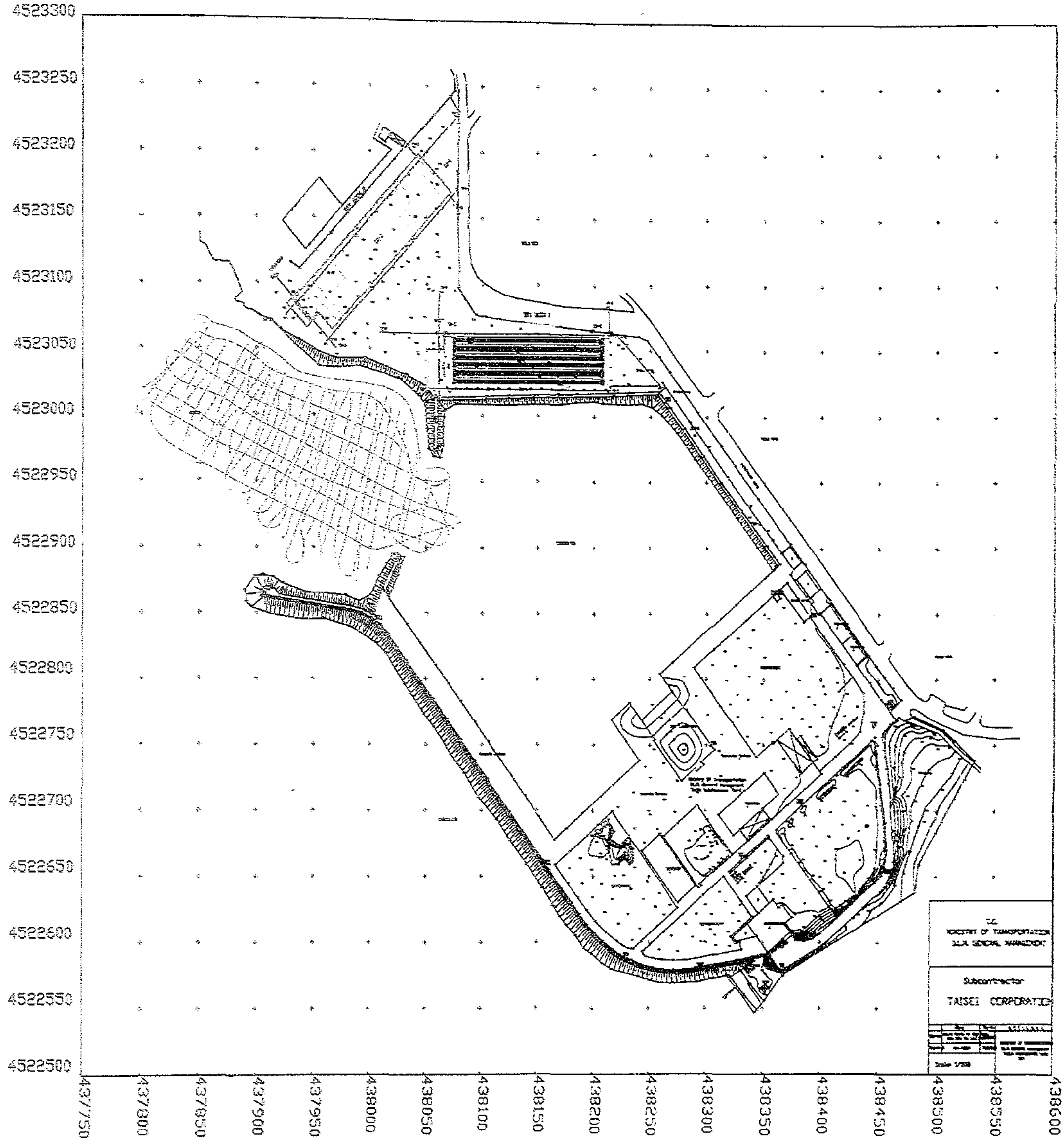

Figure 6.9. Bathymetric survey lines in D.L.H. harbor

Figure 6.10. Survey boat

Figure 6.11. Survey system in survey boat

Figure 6.12. GPS receiver at shore

Vessel positioning and data integration were achieved with HYDROpro Navigation Software. This PC based system provides real time navigation, and collection of position, time and depth soundings for subsequent analysis. Preliminary study was made before bathymetric survey, that is, coordinates of study area was defined, and vessel track planning was made. By means of RTK GPS, vessel route and position can be seen and save to the computer. Graphical display can also be drawn by HYDROpro software. The features of HYDROpro Navigation software are listed below (http://www.trimble.com/hydropronav.html):

I. Configurable geodetic database with many pre-defined ellipsoids and coordinate systems
II. Coordinate calculator for points and files
III. Built-in site calibration and adjustment
IV. Graphical vessel shape editor
V. Multiple vessels and guidance objects (targets, run lines, routes)

VI. Interactive, real-time plan view map with rotation including line up
VII. Heave and tide data from RTK
VIII. Real-time depth profile and channel cross section display
IX. User-defined echosounder annotation
X. Storage of project information and survey data in a single Microsoft Access database file
XI. Heading from dual positioning devices
XII. Fully configurable equipment timing (latency, pulse-per-second, timeouts)

Software can collect data from both echosounder and GPS receiver simultaneously and saved to the computer. Tide gauge readings are added. Offset value was zero because transducer and GPS receiver installed to the same point. All the bathymetric surveys were conducted in a good and unwind weather so that motion of the survey boat was at minimum consequently, heave, pitch and roll effects were at minimum.

Another PC-based navigation software is Hypack Survey Software for planning, conducting, editing and publishing hydrographic survey. The features of Hypack Navigation software are listed below (http://www.hypack.com/hypack.asp):

I. Supports GPS, Range-Azimuth and Range-Range Navigation System,
II. It provides interfaces for over 150 different sensors, including single beam echosounders, dual frequency echosounders, multiple transducer echosounders, multibeam sonars, gyros, heave-pitch-roll sensors, magnetometers, telemetry tide gauges, side scan sonars, flourimeters, oxygen sensors, etc.,
III. The information for each sensor is time tagged to within .001 second and logged to file for post processing
IV. The SURVEY program can be configured to display and track single vessels, multiple vessels, or the main vessel and ROVs or towfish,
V. Real time water level calculations using RTK GPS and a heave-pitch-roll sensor,
VI. Besides providing "on line" control, SURVEY also allows users to import or to mark in real time target locations. Target locations can be prepared in advance and then used to navigate to user defined locations for water quality samples or recovery of bottom mounted equipment,

VII. SURVEY allows you to "paint" the bottom with single beam, multiple transducer or multibeam depth information

6.4. Evaluation of Bathymetric Data

All collected data from GPS, echosounder and tide gauge with all corrections processed by EGHAS software. Assuming that the weights of measurements were almost equal and they were not correlated, squared mean errors were calculated, three times greater errors omitted and adjustments were completed. After interpolation of measurements, contour line maps were drawn with respect to 1:2500 Scale Map Production Standards 1974 and 1:5000 Scale Map Production Standards 2005.

The aim of this survey which has been conducted for three months was whether the topography of the seafloor in D.L.H. harbor dredged and excavated enough to achieve the secure limits. After the ninth depth measurement activity it has been seen that excavating activities could be ended.

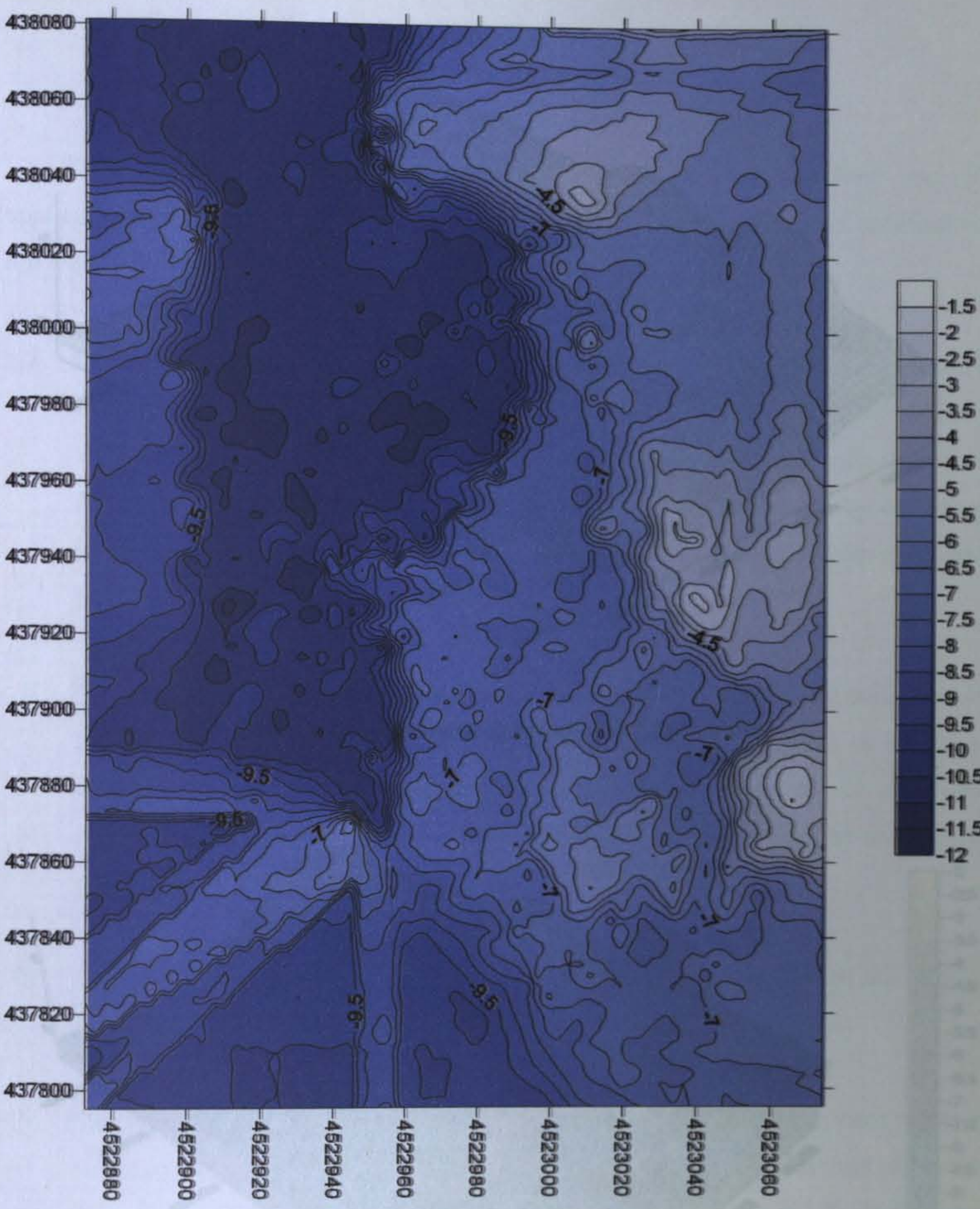

Figure 6.11. Contour line map of survey area

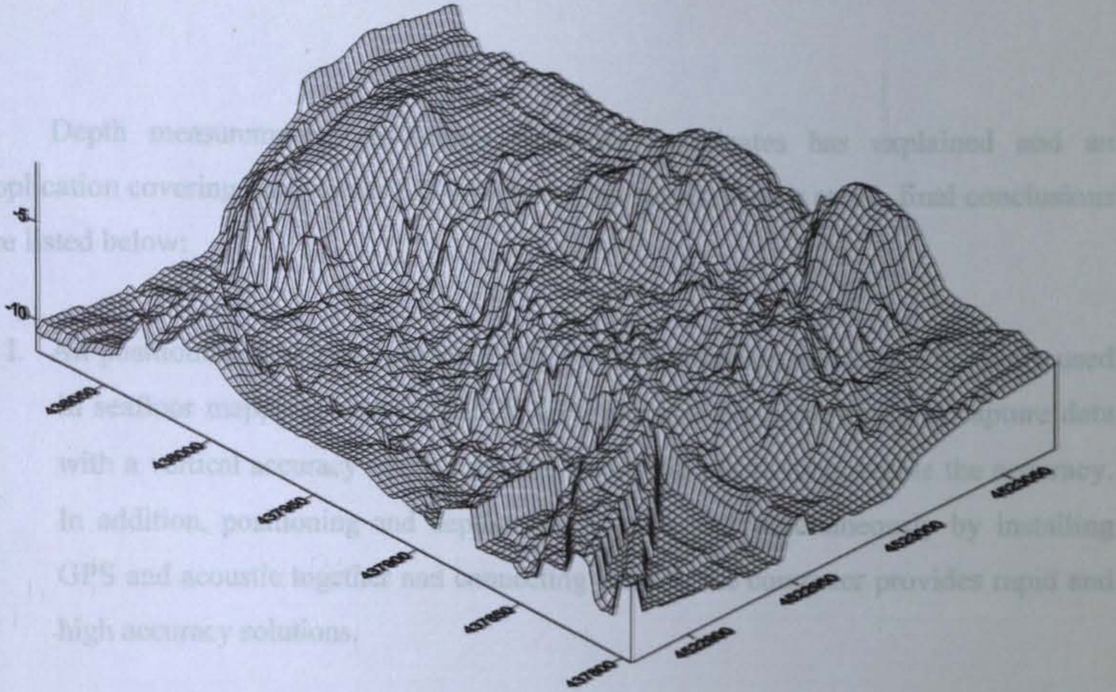

Figure 6.12. Wireframe drawing of D.L.H. harbor

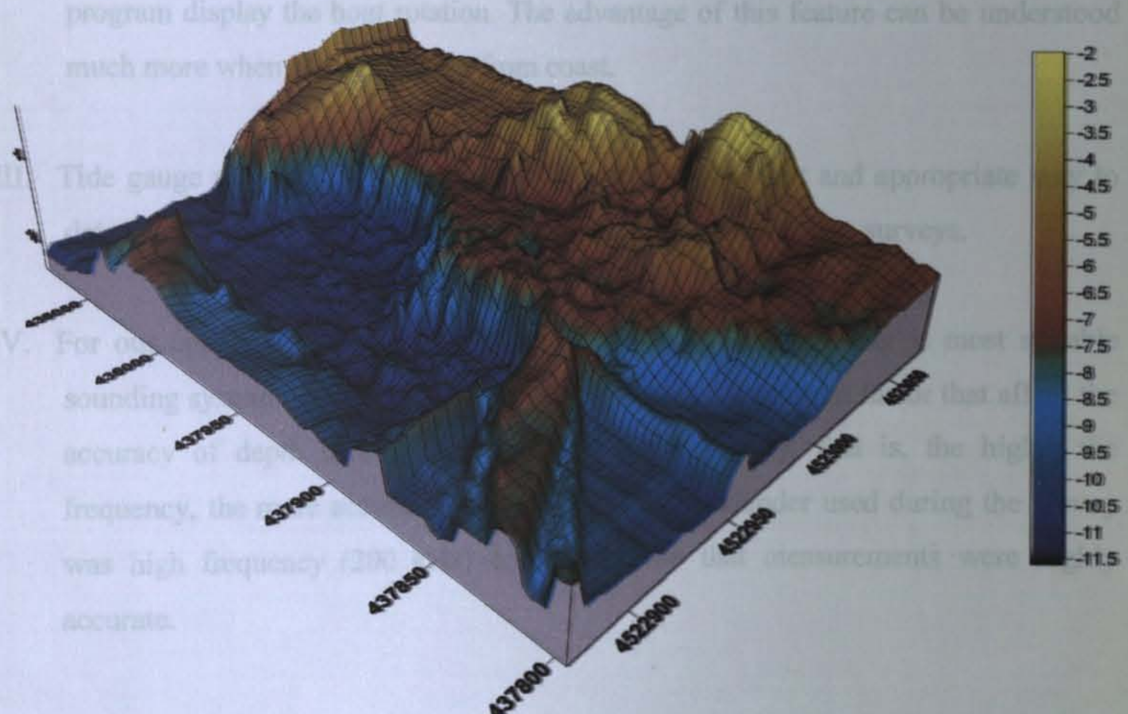

Figure 6.13. Seafloor topography of D.L.H. harbor

CONCLUSIONS

Depth measurements, positioning methods, coordinates has explained and an application covering these topics has been given in chapter 5. As a result, final conclusions are listed below:

I. All positioning activities conducted by GPS measurements, which can be easily used in seafloor mapping, especially RTK GPS provides the opportunity to capture data with a vertical accuracy of ±2-3 cm and horizontal positioning double the accuracy. In addition, positioning and depths can be measured simultaneously by installing GPS and acoustic together and connecting them to the computer provides rapid and high accuracy solutions.

II. PC based navigation software system provides real time navigation, and collection of position, time and depth soundings for subsequent analysis as well as it allows tracking the grid lines correctly. Instead of watching attention points, computer program display the bout rotation. The advantage of this feature can be understood much more when survey boat far from coast.

III. Tide gauge readings for the near shore surveys is low cost and appropriate way to determine sea level changes but it is not suitable way at offshore surveys.

IV. For our application at near shore area, single beam echosounder is most suitable sounding system which is low cost and portable unit. Important factor that affect the accuracy of depth measurement value is the frequency, that is, the higher the frequency, the more accurate the depth value. Echosounder used during the survey was high frequency (200 kHz) echosounder so that measurements were highly accurate.

APPENDIX

Table A.1. Coordinates of Detail Points in DLH Harbor, Tuzla

POINT	Y	X	Z
1	438324.100	4522604.167	1.388
2	438326.833	4522600.877	1.380
3	438322.039	4522604.371	1.357
4	438326.192	4522599.203	1.352
5	438330.120	4522600.079	1.379
6	438331.435	4522594.619	1.390
7	438344.742	4522604.834	1.464
8	438354.725	4522592.396	1.477
9	438355.071	4522591.966	1.547
10	438355.138	4522591.636	2.449
11	438349.762	4522590.922	1.440
12	438349.802	4522590.422	1.711
13	438350.082	4522589.198	2.173
14	438342.609	4522587.633	2.197
15	438342.183	4522589.448	1.427
16	438343.267	4522585.547	2.460
17	438340.352	4522583.411	2.460
18	438336.034	4522579.753	2.192
19	438338.857	4522576.558	2.269
20	438343.142	4522580.197	2.389
21	438352.645	4522568.617	2.265
22	438348.918	4522565.017	2.268
23	438352.178	4522561.718	2.164
24	438355.828	4522565.339	2.223
25	438351.730	4522555.381	1.639
26	438345.685	4522548.700	1.294
27	438343.424	4522546.583	0.420
28	438340.413	4522568.240	1.614
29	438334.342	4522560.785	1.052
30	438333.067	4522559.376	0.339
31	438331.252	4522578.788	1.303
32	438322.922	4522573.492	0.995
33	438318.905	4522574.823	0.431
34	438340.059	4522587.061	3.904
35	438337.967	4522585.516	3.833
36	438328.775	4522583.350	3.870
37	438328.290	4522584.093	3.799
38	438314.187	4522581.607	3.703
39	438293.032	4522577.947	3.701
40	438293.436	4522569.829	0.337
41	438282.457	4522576.620	3.632
42	438281.690	4522569.327	0.214
43	438273.278	4522576.255	3.645
44	438271.983	4522568.856	0.179
45	438262.958	4522577.521	3.642
46	438261.613	4522569.160	0.342
47	438252.326	4522578.336	3.636
48	438250.524	4522571.161	0.121
49	438242.322	4522580.696	3.655
50	438262.750	4522576.722	3.643
51	438240.786	4522574.151	0.417
52	438328.483	4522586.942	1.409
53	438323.729	4522593.244	1.347
54	438309.068	4522583.586	1.311
55	438307.702	4522590.496	1.333
56	438292.329	4522580.693	1.348
57	438291.334	4522587.650	1.289
58	438282.527	4522579.430	1.363
59	438282.410	4522586.721	1.360
60	438272.674	4522579.028	1.362
61	438272.634	4522586.235	1.367
62	438262.774	4522579.599	1.358
63	438262.236	4522587.083	1.320
64	438253.173	4522581.001	1.367
65	438253.479	4522588.146	1.354
66	438247.358	4522589.610	1.383
67	438244.467	4522592.802	1.441
68	438236.178	4522595.099	1.286
69	438231.765	4522595.386	1.281
70	438243.528	4522583.346	1.408
71	438235.174	4522586.628	1.428
72	438234.173	4522586.490	1.388
73	438225.167	4522590.556	1.411
74	438226.478	4522597.893	1.167
75	438243.386	4522600.714	1.339
76	438250.486	4522597.621	1.401
77	438263.100	4522607.711	1.448
78	438257.747	4522612.267	1.343
79	438279.485	4522620.846	1.466
80	438274.962	4522625.968	1.403
81	438275.392	4522630.291	1.473
82	438298.237	4522635.983	1.448
83	438291.252	4522643.123	1.499
84	438294.193	4522641.703	1.451
85	438295.067	4522644.343	1.402
86	438295.991	4522643.109	1.400
87	438315.493	4522650.092	1.423
88	438310.430	4522656.530	1.381
89	438316.123	4522650.340	1.395
90	438320.571	4522654.044	1.549
91	438321.612	4522652.907	1.509
92	438323.143	4522650.996	1.491
93	438327.835	4522645.198	1.434
94	438331.126	4522647.798	1.525
95	438332.681	4522649.095	1.629
96	438334.754	4522652.104	1.651
97	438340.727	4522657.179	1.604
98	438323.438	4522667.063	1.366
99	438335.893	4522635.124	1.437
100	438340.722	4522619.714	1.372
101	438331.598	4522631.071	1.401
102	438337.503	4522622.937	1.413
103	438330.532	4522628.557	1.345
104	438329.461	4522616.372	1.437
105	438323.637	4522622.324	1.347
106	438320.094	4522608.154	1.353
107	438314.677	4522614.168	1.428
108	438320.952	4522597.198	1.296
109	438308.375	4522605.812	1.332
110	438309.613	4522597.912	1.310
111	438304.782	4522609.472	1.311
112	438296.339	4522600.335	1.185
113	438275.974	4522592.887	1.200
114	438259.381	4522594.199	1.314
115	438270.199	4522604.746	1.301
116	438288.848	4522603.870	1.391
117	438282.855	4522614.037	1.380
118	438298.068	4522613.224	1.312
119	438292.168	4522621.717	1.355
120	438305.283	4522621.105	1.416
121	438300.241	4522628.393	1.327
122	438317.469	4522630.984	1.398
123	438312.432	4522638.426	1.284
124	438298.243	4522650.903	1.552
125	438304.098	4522655.434	1.636
126	438307.022	4522657.669	1.768
127	438311.366	4522660.882	1.646
128	438314.168	4522663.925	1.666
129	438319.334	4522670.068	1.767
130	438310.245	4522675.380	1.702

POINT	Y	X	Z
131	438309.315	4522677.130	2.044
132	438306.138	4522675.753	1.771
133	438306.450	4522673.526	1.588
134	438308.017	4522679.797	1.769
135	438306.995	4522682.007	1.841
136	438304.055	4522684.528	1.791
137	438302.110	4522688.486	1.576
138	438291.184	4522684.389	1.434
139	438296.234	4522685.649	1.483
140	438299.278	4522683.077	1.487
141	438301.867	4522679.906	1.579
142	438285.628	4522677.251	1.435
143	438304.367	4522675.723	1.636
144	438305.207	4522672.712	1.595
145	438304.676	4522667.991	1.589
146	438302.117	4522665.048	1.653
147	438299.725	4522663.796	1.650
148	438296.776	4522662.905	1.748
149	438292.555	4522663.159	1.531
150	438290.883	4522663.995	1.561
151	438350.328	4522578.924	2.497
152	438359.168	4522578.837	2.816
153	438365.523	4522577.058	2.829
154	438366.073	4522577.630	2.882
155	438368.078	4522575.301	4.517
156	438367.927	4522574.004	4.538
157	438369.765	4522575.196	4.560
158	438367.349	4522578.859	6.153
159	438366.429	4522578.258	6.203
160	438356.834	4522590.340	6.515
161	438364.204	4522599.950	6.772
162	438365.439	4522597.221	6.517
163	438365.942	4522597.806	6.513
164	438366.217	4522597.903	6.519
165	438367.331	4522596.500	6.441
166	438366.465	4522595.873	6.441
167	438370.134	4522598.683	6.462
168	438371.034	4522599.469	6.395
169	438369.032	4522600.126	6.547
170	438369.291	4522600.413	6.572
171	438367.554	4522602.646	6.751
173	438369.932	4522600.913	6.485
174	438375.421	4522605.245	6.480
175	438377.207	4522603.637	6.622
176	438373.860	4522607.706	6.731
177	438378.584	4522601.488	6.353
178	438386.057	4522600.933	6.194
179	438393.277	4522602.690	5.876
180	438399.675	4522606.372	5.629
181	438410.027	4522614.942	5.304
182	438414.704	4522618.781	5.108
183	438426.875	4522628.745	4.654
184	438438.150	4522638.053	4.224
185	438447.498	4522645.640	3.719
186	438452.127	4522638.333	3.784
187	438437.956	4522626.569	4.409
188	438428.358	4522618.542	4.776
189	438416.607	4522608.936	5.224
190	438406.068	4522600.277	5.576
191	438394.469	4522593.578	5.906
192	438383.212	4522587.355	6.006
193	438374.783	4522582.780	6.010
194	438373.995	4522581.345	5.993
195	438374.747	4522579.217	3.983
196	438389.445	4522587.228	4.379
197	438399.145	4522592.530	4.111
198	438415.439	4522601.403	4.749
199	438428.352	4522608.396	4.873
200	438433.922	4522621.053	4.690

POINT	Y	X	Z
201	438442.245	4522623.941	4.985
202	438469.572	4522630.976	5.474
203	438464.890	4522643.408	5.207
204	438450.659	4522620.570	5.194
205	438482.566	4522638.120	6.018
206	438453.001	4522629.987	4.976
207	438485.432	4522659.138	6.275
208	438462.156	4522643.519	4.832
209	438467.491	4522654.980	4.864
210	438499.886	4522683.033	6.337
211	438469.870	4522672.782	4.223
212	438478.213	4522669.350	5.508
213	438479.197	4522692.641	5.121
214	438472.667	4522652.329	5.574
215	438490.313	4522692.028	5.670
216	438466.132	4522682.144	2.765
217	438466.164	4522677.948	2.751
218	438455.740	4522642.155	3.711
219	438457.825	4522645.029	3.624
220	438452.991	4522650.733	3.498
221	438451.946	4522651.437	3.505
222	438454.047	4522652.640	3.421
223	438452.702	4522653.097	3.433
224	438455.521	4522657.109	3.197
225	438454.020	4522657.452	3.220
226	438456.708	4522663.052	2.895
227	438455.327	4522663.470	2.913
228	438457.239	4522670.193	2.605
229	438455.834	4522670.355	2.584
230	438460.280	4522649.799	3.388
231	438462.125	4522655.424	3.128
232	438463.416	4522661.873	2.786
233	438463.950	4522667.060	2.633
234	438463.616	4522685.061	2.194
235	438457.137	4522677.842	2.313
236	438455.696	4522677.930	2.416
237	438456.188	4522691.014	2.120
238	438454.709	4522690.904	2.221
239	438461.213	4522704.668	1.973
240	438454.417	4522704.529	2.008
241	438452.962	4522704.245	2.209
242	438459.043	4522721.236	1.911
243	438463.474	4522712.762	2.638
244	438465.146	4522712.725	4.273
245	438452.259	4522719.900	1.956
246	438450.795	4522719.847	2.058
247	438457.278	4522732.399	1.877
248	438450.610	4522731.353	1.897
249	438449.084	4522731.775	1.999
250	438454.835	4522746.867	1.875
251	438448.823	4522743.533	1.852
252	438447.544	4522743.000	1.968
253	438447.493	4522752.506	1.754
254	438453.393	4522756.562	1.837
255	438434.009	4522737.935	2.690
256	438435.643	4522735.093	2.045
257	438422.201	4522728.118	2.583
258	438423.976	4522726.161	1.870
259	438432.075	4522715.592	1.720
260	438411.511	4522719.406	2.541
261	438413.507	4522717.561	1.861
262	438421.159	4522707.646	1.700
263	438399.846	4522710.200	2.633
264	438401.273	4522707.946	1.819
265	438408.744	4522699.165	1.652
266	438385.350	4522698.556	2.515
267	438386.775	4522696.472	1.665
268	438394.232	4522688.369	1.606
269	438374.774	4522690.394	2.525

POINT	Y	X	Z
270	438376.387	4522688.335	1.616
271	438383.960	4522678.947	1.549
272	438367.279	4522682.790	2.492
273	438369.378	4522681.899	1.523
274	438375.625	4522674.159	1.533
275	438374.769	4522670.877	2.415
276	438384.939	4522662.957	1.574
277	438382.365	4522661.165	2.320
278	438392.490	4522649.836	2.331
279	438393.944	4522650.749	1.664
280	438401.254	4522639.234	2.394
281	438403.275	4522640.453	1.539
282	438396.844	4522672.934	1.598
283	438404.254	4522661.785	1.578
284	438407.710	4522680.741	1.626
285	438413.866	4522670.746	1.504
286	438419.425	4522689.792	1.661
287	438424.550	4522679.369	1.569
288	438429.491	4522696.481	1.561
289	438433.782	4522684.860	1.524
290	438441.343	4522703.678	1.687
291	438441.700	4522688.524	1.487
292	438447.621	4522670.789	1.869
293	438447.443	4522655.863	1.868
294	438434.560	4522662.759	1.346
295	438442.159	4522648.716	1.691
296	438421.212	4522653.254	1.431
297	438445.646	4522644.765	2.793
298	438408.551	4522645.497	1.561
299	438434.877	4522636.142	2.061
300	438430.138	4522637.855	1.468
301	438409.691	4522631.847	1.600
302	438407.870	4522631.068	2.251
303	438425.387	4522628.154	2.721
304	438422.451	4522631.113	1.905
305	438413.703	4522625.724	2.011
306	438413.426	4522624.215	2.475
307	438379.077	4522605.183	1.615
308	438375.905	4522608.853	2.663
309	438375.464	4522608.574	2.666
310	438370.880	4522614.154	2.738
311	438369.475	4522613.070	4.166
312	438368.755	4522613.956	3.905
313	438375.154	4522619.143	2.531
314	438367.099	4522628.924	2.520
315	438356.538	4522638.152	2.460
316	438359.065	4522644.610	2.488
317	438367.347	4522652.092	2.450
318	438367.716	4522633.872	2.484
319	438377.479	4522640.972	2.493
320	438377.255	4522622.303	2.497
321	438386.668	4522629.526	2.449
322	438385.708	4522611.771	2.515
323	438394.768	4522620.022	2.549
324	438407.511	4522627.653	2.350
325	438398.768	4522638.358	2.346
326	438391.254	4522647.673	2.413
327	438385.654	4522654.428	2.385
328	438374.692	4522667.833	2.378
329	438367.688	4522660.145	2.440
330	438367.507	4522665.537	2.203
331	438361.735	4522683.622	1.712
332	438361.730	4522685.587	1.734
333	438355.307	4522680.244	1.710
334	438354.450	4522681.240	1.670
335	438371.508	4522691.987	1.866
336	438377.951	4522699.330	1.823
337	438391.304	4522710.537	1.786
338	438407.689	4522723.251	1.820

POINT	Y	X	Z
339	438414.935	4522727.150	1.909
340	438420.074	4522733.186	1.735
341	438431.442	4522742.138	1.748
342	438447.161	4522756.335	1.759
343	438446.079	4522753.654	1.802
344	438444.845	4522753.390	1.788
345	438443.276	4522749.915	2.039
346	438453.822	4522758.993	1.811
347	438455.309	4522761.259	1.808
348	438460.491	4522766.232	1.880
349	438464.850	4522769.628	1.886
350	438467.587	4522771.560	2.057
351	438473.164	4522768.928	2.242
352	438479.407	4522771.720	2.561
353	438481.477	4522772.093	2.671
354	438480.537	4522766.250	2.218
355	438478.936	4522764.461	3.245
356	438495.141	4522766.298	3.009
357	438494.778	4522755.701	4.304
358	438497.677	4522758.195	3.454
359	438498.117	4522759.192	3.237
360	438499.179	4522758.628	3.378
361	438498.699	4522757.544	3.693
362	438505.940	4522761.826	3.418
363	438511.070	4522748.552	4.680
364	438516.483	4522752.991	4.649
365	438520.120	4522739.872	5.445
367	438532.756	4522738.503	6.145
368	438530.452	4522734.609	6.265
369	438524.417	4522723.949	6.332
370	438514.261	4522728.800	5.460
371	438506.397	4522716.544	5.564
372	438515.727	4522709.433	6.471
373	438492.369	4522700.551	5.582
374	438505.145	4522691.611	6.263
375	438483.033	4522707.896	5.038
376	438488.193	4522719.475	5.065
377	438494.359	4522731.872	5.011
378	438501.160	4522747.603	4.752
379	438487.636	4522753.094	4.359
380	438480.126	4522732.826	4.651
381	438476.144	4522711.891	4.862
382	438465.851	4522718.732	3.459
383	438464.201	4522718.963	2.802
384	438468.192	4522725.925	3.749
385	438463.412	4522733.203	2.924
386	438470.547	4522736.596	4.000
387	438464.406	4522749.275	3.063
388	438472.315	4522744.910	4.026
389	438464.152	4522764.692	2.352
390	438473.275	4522757.547	3.704
391	438459.754	4522776.051	1.782
392	438459.231	4522778.538	1.754
393	438461.544	4522780.396	1.786
394	438462.339	4522779.493	1.748
395	438464.276	4522781.158	1.819
396	438469.334	4522784.510	2.530
397	438461.827	4522793.801	2.424
398	438461.599	4522784.518	1.444
399	438459.790	4522783.149	1.476
400	438459.000	4522783.966	1.441
401	438456.479	4522781.913	1.798
402	438455.113	4522801.933	2.380
403	438452.460	4522785.120	1.694
404	438442.657	4522797.276	1.647
405	438447.974	4522810.689	2.527
406	438431.771	4522810.673	1.719
407	438431.298	4522811.501	1.700
408	438441.633	4522818.553	2.283

POINT	Y	X	Z
409	438415.793	4522791.094	1.318
410	438427.580	4522802.053	1.746
411	438437.708	4522789.465	1.619
412	438437.824	4522782.887	1.581
413	438437.507	4522774.288	1.635
414	438434.243	4522760.260	1.738
415	438421.952	4522760.343	1.724
416	438416.028	4522755.248	1.700
417	438413.225	4522758.531	1.766
418	438419.173	4522763.681	1.834
419	438427.112	4522751.307	1.702
420	438425.342	4522751.540	1.692
421	438412.827	4522741.545	1.649
422	438398.960	4522730.249	1.662
423	438400.517	4522728.322	1.663
424	438396.465	4522739.837	1.522
425	438393.023	4522737.051	1.607
426	438385.912	4522716.367	1.643
427	438382.795	4522728.756	1.561
428	438371.111	4522704.467	1.546
429	438363.511	4522712.930	1.500
430	438357.033	4522693.106	1.512
431	438355.958	4522694.269	1.386
432	438349.824	4522701.881	1.447
433	438382.136	4522757.380	1.396
434	438378.803	4522754.583	1.271
435	438372.375	4522762.488	1.284
436	438390.323	4522763.765	1.330
437	438383.228	4522770.025	1.257
438	438401.793	4522771.626	1.350
439	438394.297	4522780.662	1.368
440	438411.286	4522779.166	1.320
441	438403.843	4522788.589	1.303
442	438422.986	4522789.284	1.578
443	438414.280	4522797.725	1.306
444	438431.614	4522779.516	1.823
445	438420.588	4522772.295	1.771
446	438427.987	4522764.203	1.915
447	438408.335	4522764.189	1.454
448	438420.614	4522754.198	1.638
449	438396.331	4522756.616	1.376
450	438401.733	4522748.986	1.381
451	438363.977	4522626.441	2.532
452	438359.003	4522632.596	2.456
453	438355.727	4522630.040	2.464
454	438345.359	4522642.693	1.512
455	438347.355	4522644.187	1.501
456	438346.357	4522645.296	1.507
457	438349.708	4522646.092	2.106
458	438348.827	4522647.396	1.903
459	438335.047	4522646.265	1.538
460	438348.650	4522653.169	1.571
461	438343.568	4522660.257	1.699
462	438356.288	4522659.340	1.974
463	438351.919	4522669.331	1.679
464	438361.895	4522665.492	2.055
465	438368.216	4522717.473	1.372
466	438378.550	4522725.583	1.324
467	438356.505	4522730.729	1.303
468	438367.388	4522740.014	1.285
469	438343.851	4522741.339	1.331
470	438357.952	4522752.543	1.277
471	438358.551	4522751.796	1.309
472	438361.880	4522754.196	1.418
473	438350.640	4522728.876	1.448
474	438336.428	4522678.553	1.397
475	438337.284	4522677.440	1.367
476	438330.282	4522686.064	1.493
477	438324.417	4522681.412	1.479

POINT	Y	X	Z
478	438314.966	4522677.674	1.334
479	438311.838	4522680.484	1.326
480	438311.567	4522697.264	1.448
481	438301.569	4522693.258	1.268
482	438292.778	4522704.208	1.335
483	438278.241	4522722.789	1.263
484	438289.876	4522732.165	1.257
485	438291.558	4522730.180	1.264
486	438263.020	4522680.353	1.440
487	438259.768	4522682.278	1.440
488	438326.373	4522653.531	1.700
489	438328.606	4522650.798	1.548
490	438330.255	4522652.096	1.622
491	438333.455	4522653.611	1.629
492	438339.421	4522658.690	1.623
493	438335.987	4522664.351	1.649
494	438335.264	4522665.898	1.463
495	438346.240	4522622.208	1.481
496	438260.460	4522646.128	1.454
497	438243.831	4522669.424	1.420
498	438231.982	4522681.075	1.305
499	438217.026	4522699.483	1.276
500	438207.083	4522685.193	1.412
501	438210.479	4522687.711	2.783
502	438206.919	4522690.083	1.340
503	438213.446	4522689.913	2.864
504	438213.185	4522693.297	1.464
505	438214.671	4522685.733	3.503
506	438219.091	4522684.231	1.167
507	438215.399	4522678.598	0.478
508	438212.562	4522677.461	2.640
509	438214.377	4522674.012	2.302
510	438224.734	4522673.483	1.300
511	438224.581	4522671.239	2.971
512	438231.568	4522680.857	1.342
513	438229.747	4522674.218	2.916
514	438235.859	4522670.870	1.471
515	438235.227	4522661.553	1.840
516	438232.609	4522659.516	1.086
517	438228.424	4522663.401	0.900
518	438225.593	4522662.188	0.960
519	438223.001	4522659.598	1.420
520	438229.069	4522667.716	3.684
521	438222.680	4522663.786	3.181
522	438216.046	4522661.988	1.638
523	438214.619	4522671.471	2.279
524	438212.571	4522670.561	0.847
525	438209.345	4522680.681	2.281
526	438207.842	4522679.081	0.866
527	438204.865	4522680.349	0.738
528	438202.705	4522682.136	2.291
529	438199.277	4522681.179	1.194
530	438204.428	4522689.100	1.222
531	438195.922	4522681.436	1.239
532	438179.387	4522669.032	1.217
533	438166.758	4522658.817	1.244
534	438161.382	4522654.515	1.285
535	438172.225	4522641.159	1.307
536	438177.924	4522645.079	1.260
537	438181.044	4522630.311	1.302
538	438187.272	4522633.576	1.271
539	438188.328	4522621.295	1.278
540	438194.939	4522624.408	1.250
541	438194.879	4522613.557	1.310
542	438202.147	4522616.125	1.278
543	438201.664	4522606.802	1.296
544	438211.686	4522607.658	1.264
545	438209.165	4522600.564	1.325
546	438221.302	4522601.022	1.276

POINT	Y	X	Z
547	438217.479	4522594.751	1.350
550	438235.347	4522601.587	1.199
551	438242.158	4522610.437	1.230
552	438223.157	4522614.152	1.116
553	438231.329	4522621.622	1.164
554	438210.543	4522622.909	0.993
555	438217.407	4522632.513	1.187
556	438200.145	4522634.019	1.091
557	438207.710	4522644.658	1.243
558	438190.849	4522644.914	1.199
559	438199.130	4522655.212	1.121
560	438179.631	4522656.423	1.099
561	438188.682	4522663.985	1.236
562	438203.150	4522676.136	0.777
563	438206.590	4522667.378	0.644
564	438212.254	4522662.891	1.246
565	438205.795	4522664.265	1.255
566	438219.712	4522650.199	1.275
567	438227.545	4522650.814	1.278
568	438237.215	4522656.703	1.378
569	438233.979	4522640.397	1.203
570	438248.720	4522646.202	1.407
571	438245.353	4522632.521	1.170
572	438259.462	4522637.214	1.335
573	438255.837	4522626.799	1.377
574	438268.665	4522628.185	1.368
575	438263.521	4522620.998	1.317
576	438155.654	4522662.102	1.288
577	438165.939	4522677.850	1.180
578	438150.851	4522667.442	1.295
579	438136.736	4522685.072	1.226
580	438151.473	4522695.798	1.062
581	438125.554	4522698.885	1.268
582	438138.853	4522711.363	1.085
584	438114.880	4522712.015	1.223
585	438129.233	4522723.406	1.108
586	438105.291	4522724.019	1.223
587	438117.937	4522737.293	1.141
588	438094.225	4522737.833	1.257
589	438105.828	4522752.238	1.120
590	438081.554	4522753.364	1.261
591	438093.860	4522767.158	1.095
592	438069.001	4522768.940	1.166
593	438081.028	4522782.938	1.116
594	438056.478	4522784.512	1.280
595	438070.225	4522796.338	1.119
596	438045.528	4522797.926	1.324
597	438058.769	4522810.584	1.091
598	438033.281	4522813.152	1.371
599	438045.740	4522826.721	1.044
600	438025.079	4522823.532	1.231
601	438033.881	4522841.374	1.101
602	438016.655	4522833.907	1.290
603	438010.064	4522840.719	1.222
604	438017.100	4522862.042	-0.192
605	438013.789	4522866.032	1.013
606	438011.275	4522867.821	1.347
607	438001.216	4522842.941	3.085
608	438003.093	4522841.662	3.648
609	438009.621	4522837.049	3.528
610	438014.508	4522832.035	3.474
611	438028.159	4522815.070	3.472
612	438040.667	4522799.412	3.510
613	438042.265	4522798.989	3.453
614	438051.549	4522786.064	3.509
615	438062.722	4522772.330	3.511
616	438075.170	4522756.769	3.546
617	438086.122	4522743.204	3.508
618	438092.456	4522737.039	3.485

POINT	Y	X	Z
619	438102.568	4522722.828	3.478
620	438113.753	4522708.821	3.518
621	438124.910	4522695.087	3.564
622	438136.034	4522681.278	3.629
623	438142.593	4522674.684	3.619
624	438147.650	4522667.071	3.658
625	438157.940	4522654.141	3.692
626	438169.865	4522639.450	3.627
627	438170.644	4522620.007	0.060
628	438180.268	4522626.622	3.692
629	438185.713	4522619.956	3.680
630	438176.413	4522613.412	-0.202
631	438192.616	4522611.733	3.640
632	438193.177	4522612.579	3.620
633	438185.060	4522605.029	-0.136
634	438200.006	4522604.506	3.616
635	438192.312	4522595.359	-0.173
636	438207.742	4522598.125	3.683
637	438200.229	4522591.068	-0.171
638	438214.922	4522593.022	3.655
639	438209.040	4522584.012	-0.109
640	438223.700	4522588.106	3.710
641	438217.207	4522579.532	-0.242
642	438164.944	4522627.717	-0.184
643	438155.267	4522641.496	-0.252
644	438141.300	4522658.996	-0.157
645	438126.360	4522676.783	-0.182
646	438114.544	4522692.886	-0.189
647	438097.978	4522709.651	-0.210
648	438085.123	4522728.099	-0.253
649	438072.781	4522742.475	-0.156
650	438057.136	4522763.548	-0.230
651	438048.822	4522772.694	-0.159
652	438037.472	4522787.890	-0.147
653	438031.647	4522795.632	-0.254
654	438015.257	4522818.849	-0.220
655	438006.292	4522826.587	-0.245
656	437985.122	4522838.701	-0.253
657	438001.874	4522843.919	3.042
658	438000.829	4522844.833	3.780
659	437992.205	4522848.673	3.756
660	437983.197	4522850.788	3.762
661	437964.226	4522853.407	3.728
662	437959.432	4522845.403	-0.229
663	437948.917	4522855.460	3.658
664	437944.540	4522844.862	-0.175
665	437932.219	4522857.806	3.628
666	437928.535	4522846.542	-0.236
667	437919.476	4522859.596	3.626
668	437911.192	4522849.334	-0.220
669	437906.193	4522861.492	3.644
670	437904.352	4522862.684	3.618
671	437903.308	4522865.009	3.618
672	437903.607	4522866.942	3.607
673	437905.103	4522868.716	3.654
674	437907.608	4522869.289	3.628
675	437910.689	4522868.796	3.654
676	437910.604	4522867.425	2.138
677	437907.422	4522867.990	2.150
678	437906.276	4522867.718	2.146
679	437904.790	4522865.987	2.136
680	437904.836	4522864.600	2.145
681	437905.545	4522863.401	2.152
682	437906.883	4522862.775	2.153
683	437907.261	4522865.314	2.160
684	437915.752	4522868.051	2.199
685	437920.307	4522863.478	2.190
686	437919.881	4522861.005	2.187
687	437895.878	4522854.027	-0.261

POINT	Y	X	Z
688	437891.202	4522857.823	-0.240
689	437890.009	4522867.192	-0.155
690	437898.922	4522877.613	-0.131
691	437905.860	4522878.593	-0.183
692	437914.625	4522876.820	-0.089
693	437922.898	4522872.394	0.101
694	437936.211	4522858.757	2.146
695	437936.602	4522861.143	2.186
696	437955.342	4522856.068	2.183
697	437956.362	4522858.504	2.209
698	437976.339	4522853.308	2.242
699	437976.895	4522855.733	2.239
700	437983.455	4522852.314	2.207
701	437983.908	4522854.747	2.203
702	437992.508	4522850.126	2.223
703	437993.320	4522852.492	2.223
704	438001.842	4522845.963	2.318
705	438002.964	4522848.182	2.316
706	438001.993	4522846.305	1.250
707	438004.061	4522847.445	1.288
709	438176.473	4522686.411	1.153
710	438191.054	4522698.214	1.166
711	438206.472	4522710.704	1.155
712	438217.363	4522719.444	1.176
713	438229.074	4522728.958	1.174
714	438240.829	4522738.286	1.144
715	438253.634	4522746.646	1.229
716	438245.650	4522733.326	1.148
717	438262.326	4522736.088	1.337
718	438250.533	4522725.209	1.319
719	438274.090	4522722.877	1.326
720	438263.598	4522708.526	1.322
721	438286.525	4522710.349	1.302
722	438272.998	4522699.110	1.288
723	438274.898	4522690.261	1.327
724	438257.482	4522685.983	1.386
725	438245.958	4522675.633	1.413
726	438250.872	4522696.976	1.298
727	438237.527	4522686.389	1.310
728	438236.209	4522713.946	1.278
729	438222.531	4522702.407	1.246
730	438229.045	4522752.885	1.144
731	438216.089	4522769.106	1.076
732	438232.080	4522782.027	1.157
733	438242.874	4522768.786	0.052
734	438254.725	4522754.018	1.200
735	438253.947	4522753.496	1.209
736	438269.972	4522790.754	0.015
737	438281.786	4522776.349	1.209
738	438282.429	4522776.871	1.227
739	438259.460	4522804.026	1.273
740	438270.450	4522812.936	1.223
741	438289.277	4522808.945	1.194
742	438297.920	4522835.056	1.199
743	438307.285	4522823.520	1.207
744	438312.226	4522846.619	1.212
745	438321.227	4522834.775	1.241
746	438325.346	4522857.286	1.207
747	438334.497	4522845.663	1.254
748	438338.579	4522867.917	1.189
749	438348.225	4522856.596	1.315
750	438350.449	4522877.584	1.160
751	438357.758	4522883.533	-0.200
752	438362.114	4522886.890	1.358
753	438363.904	4522888.264	1.359
754	438361.003	4522866.696	1.319
755	438357.357	4522864.043	1.375
756	438360.918	4522859.625	1.468
757	438364.242	4522862.255	1.342

POINT	Y	X	Z
758	438363.938	4522869.336	1.478
759	438362.977	4522868.564	1.232
760	438370.111	4522874.437	1.349
761	438379.354	4522862.138	1.436
762	438389.723	4522848.631	1.482
763	438384.782	4522844.626	1.438
764	438383.823	4522843.814	1.386
765	438397.933	4522849.779	1.653
766	438399.338	4522850.874	1.589
767	438402.448	4522833.301	1.538
768	438411.164	4522822.692	1.550
769	438418.530	4522827.313	1.729
770	438419.923	4522811.975	1.632
771	438426.320	4522833.675	1.644
772	438397.926	4522868.984	1.565
773	438407.312	4522861.052	2.131
774	438390.108	4522862.599	1.452
775	438386.706	4522863.618	1.419
776	438378.384	4522876.991	1.374
777	438386.166	4522883.324	1.523
778	438384.966	4522888.422	1.837
779	438382.148	4522890.012	1.622
780	438373.072	4522880.338	1.469
781	438375.545	4522884.742	1.504
782	438365.505	4522896.987	1.238
783	438414.431	4522809.076	1.341
784	438405.302	4522821.442	1.407
785	438402.409	4522795.033	1.210
786	438392.010	4522810.098	1.301
787	438389.353	4522786.751	1.263
788	438380.634	4522799.361	1.236
789	438375.797	4522778.896	1.276
790	438369.880	4522790.947	1.156
791	438365.850	4522770.160	1.212
792	438356.541	4522784.480	1.123
793	438356.381	4522759.723	1.282
794	438348.949	4522771.484	1.182
795	438345.432	4522751.576	1.371
796	438336.046	4522756.642	1.294
797	438327.425	4522771.755	1.126
798	438320.810	4522780.991	1.112
799	438322.991	4522767.477	1.116
800	438312.477	4522779.687	1.183
801	438336.660	4522784.898	1.108
802	438327.574	4522788.694	1.131
803	438348.542	4522796.882	1.147
804	438337.486	4522802.438	1.118
805	438360.587	4522808.413	1.257
806	438351.051	4522816.930	1.322
807	438372.614	4522819.155	1.323
808	438366.084	4522830.108	1.317
809	438385.108	4522830.134	1.317
810	438377.224	4522843.333	1.258
811	438367.201	4522855.207	1.121
812	438353.808	4522846.786	1.092
813	438341.167	4522838.291	1.240
814	438338.445	4522824.578	1.224
815	438327.612	4522831.533	1.229
816	438325.523	4522810.568	1.184
817	438316.568	4522821.785	1.171
818	438317.765	4522799.477	1.089
819	438305.692	4522811.317	1.103
820	438304.193	4522790.508	1.212
821	438295.780	4522800.843	1.186
822	438280.572	4522801.856	1.254
823	438301.603	4522772.699	1.187
824	438291.422	4522787.041	1.236
825	438313.578	4522758.219	1.225
826	438329.344	4522740.166	1.306

POINT	Y	X	Z
827	438307.327	4522746.364	1.240
828	438312.933	4522726.519	1.340
829	438297.436	4522734.986	1.250
830	438295.580	4522737.185	1.260
831	438292.945	4522714.157	1.302
833	438279.937	4522746.349	2.841
834	438268.668	4522760.026	1.552
835	438260.217	4522770.550	0.598
836	438252.657	4522780.460	-0.174
837	438311.482	4522746.007	1.225
838	438407.321	4522857.161	1.786
839	438260.594	4523026.217	1.294
840	438267.041	4523034.281	2.204
841	438257.646	4523045.937	2.265
842	438247.277	4523058.123	2.246
843	438239.732	4523061.106	2.169
844	438226.037	4523062.406	1.794
845	438212.487	4523064.013	1.541
846	438221.682	4523054.585	1.541
847	438225.903	4523051.979	1.485
848	438228.643	4523054.736	1.588
849	438240.966	4523044.443	1.662
850	438252.230	4523033.996	1.585
851	438226.507	4523031.958	1.261
852	438230.006	4523024.924	1.227
853	438001.469	4522848.863	1.515
854	437945.326	4522865.198	-0.176
855	437961.242	4522864.706	-0.161
856	437978.984	4522862.942	-0.094
857	437990.503	4522858.784	-0.354
858	438001.465	4522863.456	-0.108
859	438009.015	4522878.234	-0.044
860	438015.695	4522887.459	-0.035
861	438020.924	4522894.631	-0.084
862	438024.603	4522895.020	-0.215
863	438030.475	4522892.103	-0.150
864	438025.053	4522878.639	-0.191
865	438021.312	4522880.462	1.344
866	438018.705	4522882.004	1.345
867	438024.430	4522892.184	1.733
868	438025.626	4522892.546	1.698
869	438026.869	4522891.797	1.661
870	438027.390	4522890.528	1.730
871	438025.708	4522888.615	1.804
872	438025.441	4522890.643	1.729
873	438372.272	4522902.108	1.509
874	438372.611	4522903.808	2.237
875	438352.502	4522902.246	1.166
876	438349.918	4522901.939	1.353
877	438344.692	4522900.986	-0.163
878	438357.132	4522906.956	1.281
879	438353.455	4522913.960	1.474
880	438326.273	4522923.644	-0.203
881	438329.597	4522927.060	1.285
882	438330.804	4522928.976	1.171
883	438337.391	4522931.161	1.244
884	438338.406	4522932.980	1.575
885	438344.870	4522938.162	2.320
886	438313.227	4522950.393	1.114
887	438311.631	4522948.971	1.249
888	438307.374	4522947.575	-0.161
889	438318.368	4522954.630	1.244
890	438324.934	4522962.750	2.265
891	438296.968	4522970.693	1.145
892	438295.228	4522969.383	1.298
893	438289.622	4522967.601	-0.266
894	438302.058	4522974.767	1.248
895	438302.098	4522977.468	1.468
896	438312.254	4522978.406	2.282

POINT	Y	X	Z
897	438280.568	4522990.961	1.082
898	438278.125	4522990.552	1.275
899	438273.516	4522987.837	-0.231
900	438285.110	4522995.870	1.267
901	438291.865	4523003.482	2.258
902	438267.827	4523006.751	1.166
903	438265.026	4523006.774	1.406
904	438260.703	4523000.765	-0.214
905	438272.211	4523011.881	1.228
906	438279.818	4523018.406	2.205
907	438258.441	4523018.594	1.156
908	438257.000	4523019.045	1.169
909	438256.330	4523019.022	1.174
910	438256.742	4523017.266	1.393
911	438252.025	4523006.816	-0.158
912	438242.454	4523009.674	-0.124
913	438231.625	4523018.411	1.157
914	438229.647	4523016.172	1.350
915	438228.183	4523009.218	-0.166
916	438211.565	4523017.818	1.137
917	438209.047	4523015.587	1.340
918	438207.550	4523009.945	-0.219
919	438200.111	4523011.396	-0.144
920	438184.583	4523017.078	1.171
921	438183.890	4523014.738	1.354
922	438183.888	4523010.698	-0.184
923	438168.553	4523016.603	1.170
924	438167.502	4523014.344	1.375
925	438169.783	4523008.855	-0.216
926	438146.089	4523015.873	1.202
927	438145.735	4523013.711	1.385
928	438145.105	4523008.958	-0.185
929	438124.119	4523015.297	1.208
930	438124.083	4523013.077	1.368
931	438122.641	4523008.056	-0.196
932	438104.143	4523014.726	1.188
933	438103.682	4523012.536	1.456
934	438105.230	4523008.371	-0.207
935	438074.772	4523013.911	1.108
936	438074.585	4523011.687	1.317
937	438077.102	4523008.832	-0.169
938	438057.171	4523013.401	1.326
939	438060.226	4523011.295	1.411
940	438066.709	4523004.281	-0.169
941	438057.077	4522995.669	1.440
942	438060.106	4522995.389	1.460
943	438064.840	4522990.996	-0.094
944	438057.076	4522976.597	1.315
945	438057.074	4522974.083	1.821
946	438058.026	4522973.036	1.822
947	438059.522	4522973.067	1.817
948	438060.511	4522974.033	1.808
949	438060.508	4522975.467	1.814
950	438060.009	4522976.413	1.803
951	438058.796	4522974.795	1.791
952	438064.599	4522976.683	-0.185
953	438062.235	4522968.003	-0.232
954	438057.126	4522968.860	-0.196
955	438052.591	4522974.556	-0.091
956	438050.823	4522989.631	-0.122
957	438049.547	4523007.239	-0.209
958	438048.917	4523022.445	1.447
959	438044.421	4523014.502	-0.228
960	438043.555	4523036.039	1.354
961	438041.451	4523054.008	1.616
962	438026.870	4523027.857	-0.110
963	438056.299	4523054.452	1.541
964	438056.445	4523044.274	1.530
965	438032.568	4523030.732	1.692

POINT	Y	X	Z
967	438013.608	4523046.845	1.609
968	437991.109	4523037.032	-0.217
969	437995.777	4523042.968	0.934
970	437971.254	4523035.920	-0.151
971	437970.174	4523042.816	1.612
972	437955.018	4523036.771	-0.162
973	437954.998	4523047.277	0.832
974	437935.883	4523057.134	0.674
975	437933.847	4523052.915	-0.219
976	437920.709	4523064.618	-0.146
977	437913.391	4523071.185	-0.113
978	437924.028	4523079.964	1.281
979	437901.509	4523075.360	-0.228
980	437916.334	4523090.859	1.373
981	437934.680	4523088.647	1.718
982	437928.630	4523100.521	1.751
983	437939.582	4523085.335	0.707
984	437937.208	4523110.505	1.649
985	437929.553	4523115.067	2.018
986	437945.426	4523096.832	1.383
987	437951.709	4523124.741	1.623
988	437963.082	4523106.861	1.595
989	437965.058	4523137.596	1.650
990	437974.756	4523123.798	1.709
991	437980.045	4523152.688	1.597
992	437988.362	4523140.891	1.726
993	437995.267	4523167.741	1.498
994	438005.076	4523154.119	1.677
995	438008.908	4523181.068	1.564
996	438018.352	4523167.019	1.443
997	438021.794	4523193.813	1.645
998	438033.913	4523182.214	1.450
999	438033.312	4523205.131	1.745
1000	438046.123	4523200.359	1.696
1001	438045.402	4523217.083	2.415
1002	438052.807	4523210.007	2.720
1003	438056.714	4523228.066	2.545
1004	438064.147	4523218.963	2.665
1005	438071.218	4523242.412	2.990
1006	438075.429	4523246.668	2.807
1007	438078.738	4523221.776	3.034
1008	438078.690	4523183.101	2.191
1009	438078.603	4523152.926	2.417
1010	438078.758	4523096.934	2.767
1011	438094.914	4523076.566	1.868
1012	438102.756	4523075.325	1.880
1013	438170.281	4523068.416	2.138
1014	438188.264	4523066.670	2.115
1015	438198.952	4523065.557	2.256
1016	438060.255	4523120.239	2.954
1017	438059.111	4523124.190	2.889
1018	438042.590	4523119.231	2.307
1019	438059.039	4523137.773	2.557
1020	438038.318	4523133.400	2.125
1021	438058.238	4523157.113	2.145
1022	438040.147	4523150.783	1.860
1023	438059.778	4523175.283	2.076
1024	438061.807	4523190.915	2.353
1025	438042.675	4523167.323	1.520
1026	438055.776	4523183.065	2.201
1027	438054.290	4523176.561	2.080
1028	438033.525	4523165.621	1.666
1029	438018.219	4523159.262	1.747
1030	438020.690	4523140.799	1.815
1031	438021.942	4523124.348	2.153
1032	438032.936	4523128.373	2.185
1033	438019.990	4523112.116	1.953
1034	438033.465	4523116.505	2.384
1035	438004.340	4523106.874	1.639

POINT	Y	X	Z
1036	438000.202	4523117.583	1.828
1037	437993.475	4523132.162	1.735
1038	437987.219	4523100.455	1.379
1039	437979.536	4523119.986	1.689
1040	437967.156	4523106.991	1.623
1041	437964.040	4523092.660	1.300
1042	437951.202	4523088.590	1.102
1043	437932.354	4523072.003	1.318
1044	437947.436	4523080.571	1.296
1045	437956.004	4523060.977	0.975
1046	437962.485	4523071.899	0.829
1047	437976.074	4523056.527	1.134
1048	437986.353	4523060.239	1.256
1049	438000.409	4523057.320	1.474
1050	437997.796	4523068.496	1.263
1051	438019.829	4523056.757	1.598
1052	438014.389	4523068.827	1.607
1053	438034.970	4523058.276	1.700
1054	438036.966	4523074.045	1.751
1055	438048.942	4523074.475	1.856
1056	438034.347	4523092.382	1.731
1057	438051.785	4523096.073	2.204
1058	438015.655	4523087.303	1.698
1059	438051.423	4523104.208	2.267
1060	438039.619	4523102.460	2.126
1061	438002.415	4523084.837	1.028
1062	438024.759	4523099.438	1.562
1063	438001.179	4523096.934	1.021
1064	438011.271	4523100.601	1.209
1065	437988.642	4523089.275	0.974
1066	437977.806	4523080.930	1.037
1067	437972.512	4523088.338	0.967
1068	438055.829	4523094.787	1.410
1069	438076.615	4523044.583	1.585
1070	438084.774	4523060.526	1.447
1071	438094.483	4523056.369	1.465
1072	438094.809	4523039.306	1.555
1073	438092.291	4523039.274	1.429
1074	438092.333	4523036.203	1.369
1075	438094.841	4523036.156	1.524
1076	438103.676	4523024.850	1.210
1077	438085.229	4523026.005	1.319
1078	438062.929	4523026.989	1.303
1079	438122.932	4523025.176	1.241
1080	438142.171	4523024.924	1.238
1081	438151.550	4523029.990	1.255
1082	438145.422	4523037.150	1.410
1083	438167.624	4523030.284	1.226
1084	438159.920	4523040.781	0.923
1085	438186.293	4523030.753	1.258
1086	438173.461	4523044.619	1.043
1087	438185.715	4523050.722	1.459
1088	438183.287	4523053.375	1.456
1089	438177.706	4523057.461	1.556
1090	438167.306	4523060.578	1.470
1092	438075.980	4523094.923	1.719
1093	438084.233	4523087.987	1.474
1094	438092.111	4523073.061	1.643
1095	438108.921	4523068.513	1.462
1096	438116.569	4523073.245	1.443
1097	438134.556	4523066.399	1.573
1098	438136.443	4523071.223	1.641
1099	438158.688	4523069.327	1.611
1100	438150.696	4523062.165	1.551
1101	438145.132	4523057.299	1.445
1102	438127.137	4523061.651	1.472
1103	438105.518	4523061.111	1.411
1104	438247.031	4523057.919	1.944
1105	438336.904	4522614.600	1.453

POINT	Y	X	Z
1107	438439.088	4522817.863	1.680
1108	438439.785	4522817.022	1.700
1109	438078.749	4523230.775	3.000

POINT	Y	X	Z

EMPLOYER'S REQUIREMENTS [25]

CHAPTER 1: GENERAL

1.8. Setting Out and Survey

1.8.1. Setting Out

I. This item supplements Conditions of Contract Sub-Clause 4.7 [Setting Out]. The lines and levels specified in the Contract are those referred to in the triangulation information provided in Site Data.

II. From these references, the Contractor is to obtain the coordinates of 3 trigonometry points close to the Site and by transference from this primary or secondary triangulation establish, protect, maintain and regularly check a system of setting out points for line and level throughout the Site. At least one trigonometry point shall be on the Asian side of the Bosphorus and one on the European side. Having selected the trigonometry points, the Contractor shall check by surveying that each point chosen is correct relative to the other points chosen. The tolerance on the distance between two fixed points shall be ± (5mm +1mm/km). The Contractor shall establish as many as are necessary but at least four permanent markers, two on the Asian Side and two on the European Side, for his own use in setting out the Works. Each marker shall have both horizontal and level fixed points determined with the precision described. The Contractor shall provide and maintain bench marks and perform surveys to monitor the settlements and horizontal movements of structures and earthworks throughout the construction period until 12 months after the Taking Over of the whole of the Works.

III. The intended purpose of this system is to provide convenient, accurate and reliable setting out and survey points for the execution of the Works and the monitoring of the condition of structures influenced by the execution of the Works.

IV. The system of setting out points shall be checked, both for internal consistency and consistency with the primary/secondary triangulation at such time intervals as to guarantee its accuracy for its intended purpose. Any setting out point that is suspected of being damaged or moved shall either be checked or taken permanently out of use and replaced.

V. In general, surveys shall be conducted when taking possession of Site and immediately before notice is given with respect to the Taking Over of the Works. In addition, intermediate surveys shall be conducted as necessary during the progress of the Works.

1.8.3. Topographic Survey

1.8.3.1. Land

I. Define and implement a topographic survey of the land along the line of the railway to a width sufficient to encompass influences of the topography on design or construction of the railway and associated structures.

II. The survey shall be presented in the form of a digital terrain model and contour plans. The tolerance on the measurement between any two markers shall be T 3 mm.

1.8.3.2. Seabed

I. Define and implement a bathymetric survey to illustrate the topography of the seabed along the line of the tunnel, to a width sufficient to encompass influences of the topography on design or construction.

II. The survey shall be presented in the form of a digital terrain model and contour plans.

1.8.5. Hydrological Survey

I. Define and implement a survey of the water conditions in the Bosphorus. The survey shall identify all aspects of the movement and physical characteristics of the water that affect design or execution of the Works. As a minimum, the survey shall provide a record of the current profile from surface to seabed at three fixed locations for at least the same 10 minute part of every hour. The records at these fixed locations shall be calibrated with current measurements taken, from surface to seabed, along the line of the tunnel in order to develop a mathematical model. This model shall be developed, calibrated and refined such that it can predict, from measurements at the fixed locations, the current at any point and at any depth along the line of the tunnel.

II. The survey and the model are required to provide the information needed to enable reliable predictions to be made for the design and execution of the Works and to establish the reference conditions for current.

III. The survey shall commence within 28 days of the Commencement Date and shall continue until such time as the work on or under water is complete.

IV. Data from the survey shall be modeled and the predicative capabilities of the model developed, refined and tested to enable adequate periods of suitable working conditions related to current to be predicted. The raw data and model report shall be submitted to the Employer, if so requested.

REFERENCES

1. Carleton, C. M. and P. J. Cook, 2000, *Continental Shelf Limits - The Scientific and Legal Interface*, Oxford University Press, London.

2. Ingham, A. E., 1975, *Sea Surveying (Text)*, John Wiley & Sons, New York.

3. Hekimoğlu, Ş., D. U. Şanlı, 1993, "Düşey Datum Belirlemede Sorunlar ve Aşamalı Yaklaşım", *Türkiye Ulusal Jeodezi ve Jeofizik Birliği (TUJJB) Genel Kurul Bildiri Kitabı*, June 08-11, Page 21-46, Ankara

4. Köprülü, K., 2006, *Türkiye Denizleri Karşılaştırmalı Sualtı Akustik Modellemesi*, M.S. Thesis, Institute of Marine Science and Management, Istanbul University.

5. Aydın, Ö., H. Erkaya, R. G. Hoşbaş and N. O. Aykut, 2005, *Hidrografik Ölçmelerde Standartların Önemi*, Yıldız Technical University.

6. Alkan, R. M., 1998, *Presizyonlu Hidrografik Ölçmelerde Bat-Çık Etkisinin GPS Yöntemi ile Belirlenmesi*, Ph.D. Thesis, İstanbul Technical University.

7. Özgen, G. M. and E. Algül, 1977, *Mühendislik Ölçmeleri, 1-Hidrografik Ölçmeler*, İstanbul Technical University Press, İstanbul.

8. Algül, E., 1983, *Akustik İskandil Yöntemi ve Ölçülerin Değerlendirilmesi*, İstanbul Technical University Magazine, Vol.41, No.3-4.

9. Chapelon, A. and E. Kammerer, 2005, *Benefits of Using Highgrade True INS for Hydrography*, http://www.thsoa.org/hy05/alt_2.pdf

10. Ingham, A. E., 1992, *Hydrography for the Surveyor and the Engineer*, Oxford Blackwell Scientific Publications.

11. Juan, J. M., M. H. Pajares and J. Sanz, 1998, *GPS Data Processing Lecture notes,* Universitat Politècnica de Catalunya, Barcelona, Spain.

12. Eren, K. and T. Uzel, 1995, *GPS Ölçmeleri*, Yıldız Technical University.

13. Ferrari, R. L., P. Weghorst, 1997, *Hydrographic Survey Method and Equipment*, http://www.sci.sdsu.edu/salton/saltcont.htm, Colorado

14. US Army Corps of Engineers, 2002, *Engineering and Design - Hydrographic Surveying Manual*, http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-2-1003/

15. Short, N. M., 2006, *Remote Sensing Tutorial*, Nasa, http://rst.gsfc.nasa.gov/Front/tofc.html

16. Örmeci, C., 1987, *Uzaktan Algılama*, İstanbul Technical University, Faculty of Civil Engineering.

17. Crum, S., 1997, *Aerial Photography and Remote Sensing*, http://www.colorado.edu/geography/gcraft/notes/remote/remote_ftoc.html, Department of Geography, University of Texas.

18. Dinn, D. F., G. Henderson, R. Courtney and J. Bradford, *New Technologies for Near Shore Mapping*, http://www.mar.dfo-mpo.gc.ca/science/review/e/pdf/new_technologies .pdf

19. Banic, J.,G. Canningham, 1999, *Airborne Laser Bathymetry*, http://shoals.sam.usace.army.mil/downloads/Publications/32Banic_Cunningham_98.pdf, Toronto.

20. Doğan, E. and B. Alpar, 1994, *Deniz ve Göllerde Derinlik Ölçme Sistem ve Yöntemleri*, İstanbul University Press, İstanbul.

21. Baş, D., 1998, *Hidrografide presizyonlu derinlik belirlemesi için akustik iskandil ölçülerine getirilecek düzeltme ve indirgemelerin incelenmesi,* M.S. Thesis, İstanbul Technical University Press, İstanbul.

22. Dana, P. H., 1995, *Coordinate Systems Overview*, http:// www.colorado.edu/geography/ gcraft/notes/coordsys/coordsys_ftoc.html, Department of Geography, University of Texas.

23. Gürdal, M. A., S.Ceylan, 2005, *Büyük Ölçekli Çalışmalarda Güncellenmiş Türkiye Jeoidinin (TG-99A) Doğrudan Kullanılabilirliğinin Araştırılması*, Jeodezi Daire Başkanlığı, Harita Genel Komutanlığı, Ankara.

24. Ünlütepe, A., 2006, *Marmaray BC1 Project and Surveying Activities*, Geodesy Department, Kandilli Observatory and Earthquake Research Institute, Boğaziçi University.

25. *Marmaray Contract BC1 Employer's Requirements Chapter 1*, Gama Nurol Corporation, Istanbul.

REFERENCES

Algül, E., 1983, *Akustik İskandil Yöntemi ve Ölçülerin Değerlendirilmesi*, İstanbul Technical University Magazine, Vol.41, No.3-4.

Alkan, R. M., 1998, *Presizyonlu Hidrografik Ölçmelerde Bat-Çık Etkisinin GPS Yöntemi ile Belirlenmesi*, Ph.D. Thesis, İstanbul Technical University.

Aydın, Ö., H. Erkaya, R. G. Hoşbaş and N. O. Aykut, 2005, *Hidrografik Ölçmelerde Standartların Önemi*, Yıldız Technical University.

Banic, J.,G. Canningham, 1999, *Airborne Laser Bathymetry*, http:// shoals.sam.usace.army.mil/downloads/Publications/32Banic_Cunningham_98.pdf, Toronto.

Baş, D., 1998, *Hidrografide presizyonlu derinlik belirlemesi için akustik iskandil ölçülerine getirilecek düzeltme ve indirgemelerin incelenmesi,* M.S. Thesis, İstanbul Technical University Press, İstanbul.

Carleton, C. M. and P. J. Cook, 2000, *Continental Shelf Limits - The Scientific and Legal Interface*, Oxford University Press, London.

Chapelon, A. and E. Kammerer, 2005, *Benefits of Using Highgrade True INS for Hydrography*, http://www.thsoa.org/hy05/alt_2.pdf

Crum, S., 1997, *Aerial Photography and Remote Sensing*, http://www.colorado.edu/ geography/gcraft/notes/remote/remote_ftoc.html, Department of Geography, University of Texas.

Dana, P. H., 1995, *Coordinate Systems Overview*, http:// www.colorado.edu/geography/ gcraft/notes/coordsys/coordsys_ftoc.html, Department of Geography, University of Texas.

Dinn, D. F., G. Henderson, R. Courtney and J. Bradford, *New Technologies for Near Shore Mapping*, http://www.mar.dfo-mpo.gc.ca/science/review/e/pdf/new_ technologies .pdf

Doğan, E. and B. Alpar, 1994, *Deniz ve Göllerde Derinlik Ölçme Sistem ve Yöntemleri*, İstanbul University Press, İstanbul.

Marmaray Contract BC1 Employer's Requirements Chapter 1, Gama Nurol Corporation, Istanbul.

Eren, K. and T. Uzel, 1995, *GPS Ölçmeleri*, Yıldız Technical University.

Ferrari, R. L., P. Weghorst, 1997, *Hydrographic Survey Method and Equipment*, http://www.sci.sdsu.edu/salton/saltcont.htm, Colorado

Gürdal, M. A., S.Ceylan, 2005, *Büyük Ölçekli Çalışmalarda Güncellenmiş Türkiye Jeoidinin (TG-99A) Doğrudan Kullanılabilirliğinin Araştırılması*, Jeodezi Daire Başkanlığı, Harita Genel Komutanlığı, Ankara.

Hekimoğlu, Ş., D. U. Şanlı, 1993, "Düşey Datum Belirlemede Sorunlar ve Aşamalı Yaklaşım", *Türkiye Ulusal Jeodezi ve Jeofizik Birliği (TUJJB) Genel Kurul Bildiri Kitabı*, June 08-11, Page 21-46, Ankara

Ingham, A. E., 1975, *Sea Surveying (Text)*, John Wiley & Sons, New York.

Ingham, A. E., 1992, *Hydrography for the Surveyor and the Engineer*, Oxford Blackwell Scientific Publications.

Juan, J. M., M. H. Pajares and J. Sanz, 1998, *GPS Data Processing Lecture Notes,* Universitat Politècnica de Catalunya, Barcelona, Spain.

Köprülü, K., 2006, *Türkiye Denizleri Karşılaştırmalı Sualtı Akustik Modellemesi*, M.S. Thesis, Institute of Marine Science and Management, Istanbul University.

Örmeci, C., 1987, *Uzaktan Algılama*, İstanbul Technical University, Faculty of Civil Engineering.

Özgen, G. M. and E. Algül, 1977, *Mühendislik Ölçmeleri, 1-Hidrografik Ölçmeler*, İstanbul Technical University Press, İstanbul.

Short, N. M., 2006, *Remote Sensing Tutorial*, Nasa, http://rst.gsfc.nasa.gov/Front/ tofc.html

US Army Corps of Engineers, 2002, *Engineering and Design - Hydrographic Surveying Manual*, http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-2-1003/

Ünlütepe, A., 2006, *Marmaray BC1 Project and Surveying Activities*, Geodesy Department, Kandilli Observatory and Earthquake Research Institute, Boğaziçi University.

REFERENCES NOT CITED

Alkan, R. M., *GPS Single Point Positioning Without Selective Availability*, Department of Geodesy and Photogrammetry Engineering, İstanbul Technical University,2001.

Balk H., and T. Lindem, *Fish Detection in Rivers with Split-beam Sonars*, June 27-30, 25th Scandinavian Symposium, Ustaoset, 2002.

Crum, S., *Aerial Photography and Remote Sensing*, http:// www.colorado.edu/ geography/gcraft/notes/remote/remote_ftoc.html, Department of Geography, University of Texas, 1997.

Dana, P. H., *Coordinate Systems Overview*, http:// www.colorado.edu/geography/ gcraft/notes/coordsys/coordsys_ftoc.html, Department of Geography, University of Texas, 1995.

Data Collection Methods, http://facility.unavco.org/project_support/campaign/training/ collect_meth.html, 2006.

Fundamentals of Electro Acoustics, http://www.massa.com/fundamentals.htm, 2006.

GPS and GLONASS Overview, Geoscience Australia, Australian Government, http://www.ga.gov.au/geodesy/gps/, 2006.

Glonass and GPS, Space Today Online, http://www.spacetoday.org/ Satellites/GLONASS.html, 2006.

GPS Survey Methods, Unavco Consortium, http://facility.unavco.org/ project_support/campaign/training/collect_meth.html, 2005.

GPS System Overview, http://www.csr.utexas.edu/texas_pwv/midterm/gabor/gps.html, University of Texas.

GPS Tutorial, Trimble Navigation Ltd., http://www.trimble.com/gps/, 2006.

Hydrographic IHO Standards, International Hydrographic Organization http://www.hypack.com/ newsletter/4_04/pat_3.htm

Juan, J. M., M. H. Pajares and J. Sanz, *GPS Data Processing Lecture Notes* Universitat Politècnica de Catalunya, Barcelona, Spain, 1998.

Plane Surveying Equipments, Department of Geomatics Web Site, The University of Melbourne, http://www.sli.unimelb.edu.au/planesurvey/prot/equip/equip5-2.html

Sea Level Rise, Wikipedia, http://en.wikipedia.org/wiki/Sea_level_change, 2006.

Single Beam Acoustic Depth Measurement Techniques, US Army Corps and Engineers, Washington, "Single Beam Acoustic Depth Measurement Techniques", US, http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-2-1003/c-9.pdf

Sounding Methods, http://mail.vssd.nl/hlf/a033Ch11.pdf

Sources of Errors in GPS, Kowoma GPS System Explained Web Site, http://www.kowoma.de/en/gps/errors.htm, 2005.

Techniques of Surveying, Department of Education and the Arts, Queensland Government Web Site, http://education.qld.gov.au/curriculum/area/maths/compass/html/ surveying/sutec.html

Temperature, Salinity and Density, http://oceanworld.tamu.edu/resources/ocng_textbook/ chapter06/chapter06_01.htm

Turgut B., and E. Tuşat, *GPS ile Bir Ağ Çalışması*, Jeodezi, Jeoinformasyon ve Arazi Yönetimi Magazine, Vol.93, 2005.