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**Кафедра иностранных языков**

# ИНОСТРАННЫЙ ЯЗЫК
# ПРИКЛАДНАЯ ГЕОДЕЗИЯ
# (ИНЖЕНЕРНАЯ ГЕОДЕЗИЯ)

***Методические указания к практическим занятиям для студентов специальности 21.05.01***

**FOREIGN LANGUAGE**

**ENGINEERING GEODESY**

САНКТ-ПЕТЕРБУРГ

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**ИНОСТРАННЫЙ ЯЗЫК. Прикладная геодезия (инженерная геодезия). Foreign language. Engineering Geodesy:** Методические указания к практическим занятиям. / Санкт-Петербургский горный университет. Сост. *Ю.В. Борисова*. СПб, 2022. 34 с.

Методические указания предназначены для студентов, обучающихся по специальности 21.05.01 «Прикладная геодезия», специализации «Инженерная геодезия» и согласованы с программой по иностранному языку для студентов неязыковых вузов.

Предлагаемый материал направлен на совершенствование навыков профессионально-ориентированного чтения на английском языке. Данные методические указания включают тексты на языке оригинала, а также разработанный комплекс лексико-грамматических упражнений и заданий, способствующих развитию речевой, языковой, социокультурной и информационной компетенций студентов, необходимых для общения в сфере профессиональных интересов.

Предназначены для практических занятий по английскому языку со студентами 2-го курса.

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## ПРЕДИСЛОВИЕ

Данные методические указания предназначены для учебно-методического сопровождения курса английского языка для студентов неязыковых вузов, обучающихся по специальности 21.05.01 «Прикладная геодезия», специализации «Инженерная геодезия».

Изучение материала преследует цель развития навыков и умений просмотрового и изучающего чтения текстов по направлению подготовки, а также их перевода на русский язык с последующим использованием полученной информации для речевой практики; овладение студентами иноязычной коммуникативно-речевой компетенцией, позволяющей будущему специалисту осуществлять профессиональную коммуникацию; формирование активного словарного запаса, который включает наиболее употребительные английский термины и выражения по теме «Engineering Geodesy».

Задания для чтения и перевода составлены на материале текстов в оригинале и сопровождаются специально разработанными лексико-грамматическими упражнениями, направленными на активизацию когнитивной деятельности обучающихся, освоение нового лексическо-грамматического материала, и способствуют развитию коммуникативных навыков в сфере профессионального общения на английском языке.

## UNIT 1. HISTORY OF GEODESY

**I. Read the text and answer the following questions.**

1. What interested man about the earth for many centuries?
2. What did Pythagoras and Anaximenes consider the earth to be in shape?
3. What measurements did Eratosthenes make and what did he observe?
4. What unit of measurements did Eratosthenes use in his calculations?
5. Whose maps influenced the cartographers of the middle ages?
6. What measurements did Picard and his followers perform?
7. What controversy was between French and English scientists?
8. What conclusion was made during geodetic expedition to Peru?

### HISTORY OF GEODESY

Man has been concerned about the earth on which he lives for many centuries. During very early times this concern was limited, naturally, to the immediate vicinity of his home; later it expanded to the distance of markets or exchange places; and finally, with the development of means of transportation man became interested in his whole world.

Much of this early "world interest" was evidenced by speculation concerning the size, shape, and composition of the earth. The early Greeks, in their speculation and theorizing, ranged from the flat disc advocated by Homer to Pythagoras' spherical figure-an idea supported one hundred years later by Aristotle.

Pythagoras was a mathematician and to him the most perfect figure was a sphere. He reasoned that the gods would create a perfect figure and therefore the earth was created to be spherical in shape. Anaximenes, an early Greek scientist, believed strongly that the earth was rectangular in shape. Since the spherical shape was the most widely supported during the Greek Era, efforts to determine its size followed.

Plato determined the circumference of the earth to be 40,000 miles while Archimedes estimated 30,000 miles. Plato's figure was a guess and Archimedes' a more conservative approximation.

Meanwhile, in Egypt, a Greek scholar and philosopher, Eratosthenes, set out to make more explicit measurements. He had observed that on the day of the summer solstice, the midday sun shone to the bottom of a well in the town of Syene (Aswan).

At the same time, he observed the sun was not directly overhead at Alexandria; instead, it cast a shadow with the vertical equal to 1/50th of a circle (7° 12'). The actual unit of measure used by Eratosthenes was called the "stadia." No one knows for sure what the stadia that he used is in today's units.

The measurements given above in miles were derived using one stadia equal to one-tenth statute mile. It is remarkable that such accuracy was obtained in view of the fact that most of the "known" facts and his observations were incorrect.

Another ancient measurement of the size of the earth was made by the Greek, Posidonius. He noted that a certain star was hidden from view in most parts of Greece but that it just grazed the horizon at Rhodes. Posidonius measured the elevation of the same star at Alexandria and determined that the angle was 1/48th of circle. Assuming the distance from Alexandria to Rhodes to be 500 miles, he computed the circumference of the earth as 24,000 miles. While both his measurements were approximations when combined, one error compensated for another and he achieved a fairly accurate result.

Revising the figures of Posidonius, another Greek philosopher determined 18,000 miles as the earth's circumference. This last figure was promulgated by Ptolemy through his world maps. The maps of Ptolemy strongly influenced the cartographers of the middle ages.

It is probable that Columbus, using such maps, was led to believe that Asia was only 3 or 4 thousand miles west of Europe. It was not until the 15th century that his concept of the earth's size was revised.

During that period the Flemish cartographer, Mercator, made successive reductions in the size of the Mediterranean Sea and all of Europe which had the effect of increasing the size of the earth. The telescope, logarithmic tables, and the method of triangulation were contributed to the science of geodesy during the 17th century. In the course of the century, the Frenchman, Picard, performed an arc measurement that is modern in some respects.

He measured a base line by the aid of wooden rods, used a telescope in his angle measurements, and computed with logarithms. Cassini later continued Picard's arc northward to Dunkirk and southward to the Spanish boundary. Cassini divided the measured arc into two parts, one northward from Paris, another southward.

When he computed the length of a degree from both chains, he found that the length of one degree in the northern part of the chain was shorter than that in the southern part. This unexpected result could have been caused only by an egg-shaped earth or by observational errors.

The results started an intense controversy between French and English scientists. The English claimed that the earth must be flattened, as Newton and Huygens had shown theoretically, while the Frenchmen defended their own measurement and were inclined to keep the earth egg-shaped.

To settle the controversy, once and for all, the French Academy of Sciences sent a geodetic expedition to Peru in 1735 to measure the length of a meridian degree close to the Equator and another to Lapland to make a similar measurement near the Arctic Circle.

The measurements conclusively proved the earth to be flattened, as Newton had forecast. Since all the computations involved in a geodetic survey are accomplished in terms of a mathematical surface (reference ellipsoid) resembling the shape of the earth, the findings were very important. (http://www.ngs.noaa.gov/PUBS_LIB/Geodesy4Layman/TR80003A.HTM#ZZ4)

**II. Mark the following sentences True or False.**

1. Pythagoras believed that the earth was created to be rectangular in shape.
2. Archimedes determined the circumference of the earth to be 30000miles.
3. Measuring the distance from Alexandria to Rhodes and computing the circumference of the earth Posidonius achieved a fairly accurate result.
4. Columbus was led to believe that Asia was 3 or 4 thousand miles east of Europe.
5. Having computed the length of a degree from both chains Cassini found that the length of one degree in the southern part of the chain was longer than that in the northern part.
6. In 1737 a geodetic expedition was sent to Peru to measure the length of a meridian degree close to the Equator.

**III. Translate the following sentences into English.**

1.Геодезия — наука об измерениях, проводимых в целях изучения формы, размеров и внешнего гравитационного поля Земли, изображения отдельных частей ее поверхности в виде планов, карт и профилей, а также решения инженерных задач на местности.

2. Геодезические измерения для разделения поверхности Земли на участки производились в Египте, Китае и других странах за много столетий до нашей эры.
3. Развитию и совершенствованию методов геодезических работ способствовали научные достижения в области математики, физики, инструментальной техники.
4. Первые указания на выполнение геодезических измерений в России относятся к XI в., когда между Керчью и Таманью по льду была измерена ширина Керченского пролива.
5. Работы по составлению карт получили большое развитие при Петре I.
6. После Отечественной войны 1812 г., выявившей плохое обеспечение России картами, последовала организация топографических съемок, которые предназначались в первую очередь для военных целей.
7. Российские геодезисты под руководством Ф. Н. Красовского получили новые параметры фигуры Земли.
8. Ученым М. С. Молоденским была разработана новая теория изучения фигуры Земли и ее внешнего гравитационного поля, поставившая советскую геодезию в области теории решения ее основной научной проблемы на первое место в мире.

## UNIT 2. GEODETIC SURVEYING TECHNIQUES

**I. Read the text and answer the following questions.**

1. What are traditional surveying techniques? What are they used for?
2. How are astronomic positions obtained?
3. How is astronomic latitude defined?
4. What is astronomic longitude? How is it measured?
5. How do optical instruments astronomic observations made by work (function)?

6. What are the differences between the plane survey and triangulation?
7. What is the principle of triangulation based on?
8. What are four general orders of triangulation?
9. When is each triangulation order used?
10. Which accuracy should four orders of triangulation indicate?

## GEODETIC SURVEYING TECHNIQUES
## (Part I)

Four traditional surveying techniques (1) astronomic positioning, (2) triangulation, (3) trilateration, and (4) traverse are in general use for determining the exact positions of points on the earth's surface.

### Horizontal positioning
### Astronomic Position Determination

Astronomic positioning is the oldest positioning method. It has been used for many years by mariners and, more recently, by airmen for navigational purposes.

Geodesists must use astronomic positions along with other types of survey data such as triangulation and trilateration to establish precise positions. As the name implies, astronomic positions are obtained by measuring the angles between the plumb line at the point and a star or series of stars and recording the precise time at which the measurements are made. After combining the data with information obtained from star catalogues, the direction of the plumb line (zenith direction) is computed.

While geodesists use elaborate and very precise techniques for determining astronomic latitude, the simplest method, in the northern hemisphere, is to measure the elevation of Polaris above the horizon of the observer.

Astronomic latitude is defined as the angle between the perpendicular to the geoid and the plane of the equator. Astronomic longitude is the angle between the plane of the meridian at Greenwich (Prime Meridian) and the astronomic meridian of the point.

Actually, it is measured by determining the difference in time-the difference in hours, minutes, and seconds between the time a specific star is directly over the Greenwich meridian and the time the same star is directly over the meridian plane of the point.

Astronomic observations are made by optical instruments-theodolite, zenith camera, prismatic astrolabe-which all contain leveling devices.

When properly adjusted, the vertical axis of the instrument coincides with the direction of gravity and is, therefore, perpendicular to the geoid. Thus, astronomic positions are referenced to the geoid.

## Triangulation

The most common type of geodetic survey is known as triangulation. It differs from the plane survey in that more accurate instruments are used; instrumental errors are either removed or predetermined. Another very important difference is that all of the positions established by triangulation are mathematically related to each other.

Basically, triangulation consists of the measurement of the angles of a series of triangles. The principle of triangulation is based on simple trigonometric procedures. If the distance along one side of a triangle and the angles at each end of the side are accurately measured, the other two sides and the remaining angle can be computed.

Normally, all of the angles of every triangle are measured for the minimization of error and to furnish data for use in computing the precision of the measurements.

Also, the latitude and longitude of one end of the measured side along with the length and direction (azimuth) of the side provide sufficient data to compute the latitude and longitude of the other end of the side.

There are four general orders of triangulation.

First-Order (Primary Horizontal Control) is the most accurate triangulation. It is costly and time-consuming using the best instruments and rigorous computation methods. First-Order triangulation is usually used to provide the basic framework of horizontal control for a large area such as for a national network.

It has also been used in preparation for metropolitan expansion and for scientific studies requiring exact geodetic data. Its accuracy should be at least one part in 100,000. Second-Order, Class I (Secondary Horizontal Control) includes the area networks between the First-Order arcs and detailed surveys in very high value land areas.

It should indicate an accuracy of at least one part in 50,000. The demands for reliable horizontal control surveys in areas which are not in a high state of development or where no such development is anticipated in the near future justifies the need for a triangulation classified as Second-Order, Class II (Supplemental Horizontal Control).

This class is used to establish control along the coastline, inland waterways and interstate highways. The control data contributes to the National Network and is published as part of the network. The minimum accuracy allowable in Class II of Second-Order is one part in 20,000. Third-Order, Class I and 17 Class II (Local Horizontal Control) is used to establish control for local improvements and developments, topographic and hydrographic surveys, or for such other projects for which they provide sufficient accuracy. Its accuracy should be at least one part in 10,000 for Class I and one part in 5,000 for Class II.

The sole accuracy requirement for Fourth-Order triangulation is that the positions be located without any appreciable errors on maps compiled on the basis of the control. Normally, triangulation is carried out by parties of surveyors occupying preplanned locations (stations) along the arc and accomplishing all the measurements as they proceed.

(adopted from http://www.ngs.noaa.gov/PUBS_LIB/Geodesy4Layman/TR80003B.HTM)

**II. Give English equivalents for the following word combinations.**

1. определять точное положение 2. измерение углов 3. широта 4. долгота 5. правильно установленный 6. исключать ошибки 7. требовать точные сведения 8. подтверждать необходимость 9. обеспечивать точность 10. группа исследователей

**III. Give Russian equivalents for the following word combinations.**

1. surveying techniques 2. to measure the elevation 3. the Greenwich meridian 4. a leveling device 5. to be related to each other 6. to be costly and time-consuming 7. to provide the basic framework 8. the area networks 9. to establish control 10. to accomplish all the measurements

## GEODETIC SURVEYING TECHNIQUES
## (Part 2)

### Trilateration

Another surveying method involves the use of radar and aircraft. The SHORAN, HIRAN and SHIRAN electronic distance measuring systems have been applied to performing geodetic surveys by a technique known as trilateration.

Since very long lines (to 500 miles) could be measured by these systems, geodetic triangulation networks have been extended over vast areas in comparatively short periods of time.

In addition, the surveys of islands and even continents separated by extensive water barriers have been connected by the techniques.

1. Traverse The simplest method of extending control is called traverse. The system is similar to dead reckoning navigation where distances and directions are measured. In performing a traverse, the surveyor starts at a known position with a known azimuth (direction) to another point and measures angles and distances between a series of survey points.

2. If the traverse returns to the starting point or some other known position, it is a closed traverse, otherwise the traverse is said to be open. The traverse consists of a series of high-precision length, angle and astronomic azimuth determinations running approximately east-west and north-south through the conterminous states, forming somewhat rectangular loops.

### Vertical positioning

Vertical surveying is the process of determining heights-elevations above the mean sea level surface. The geoid corresponds to the mean level of the open sea. In geodetic surveys executed primarily for mapping purposes, there is no problem in the fact that geodetic positions are referred to an ellipsoid and the elevations of the positions are referred to the geoid.

3. Precise geodetic leveling is used to establish a basic network of vertical control points. From these, the height of other positions in the survey can be determined by supplementary methods. The mean sea level

surface used as a reference (vertical datum) is determined by obtaining an average of the hourly water heights for a period of several years at tidal gauges.

There are three leveling techniques-differential, trigonometric, and barometric which yield information of varying accuracy. Differential leveling is the most accurate of the three methods. With the instrument locked in position, readings are made on two calibrated staffs held in an upright position ahead of and behind the instrument. The difference between readings is the difference in elevation between the points.

The exact elevation of at least one point in a leveling line must be known and the rest computed from it. Trigonometric leveling involves measuring a vertical angle from a known distance with a theodolite and computing the elevation of the point.

It is, therefore, a somewhat more economical method but less accurate than differential leveling. It is often the only practical method of establishing accurate elevation control in mountainous areas. In barometric leveling, differences in height are determined by measuring the difference in atmospheric pressure at various elevations.

Air pressure is measured by mercurial or aneroid barometers, or a boiling point thermometer. Although the degree of accuracy possible with this method is not as great as either of the other two, it is a method which obtains relative heights very rapidly at points which are fairly far apart. It is widely used in the reconnaissance and exploratory surveys where more exacting measurements will be made later or are not required.

With the angular measurements, the direction of each line of the traverse can be computed; and with the measurements of the length of the lines, the position of each control point computed.

The optical instrument used for leveling contains a bubble tube to adjust it in a position parallel to the geoid. When properly "set up" at a point, the telescope is locked in a perfectly horizontal (level) position so that it will rotate through a 360 arc.

However, geodetic data for missiles requires an adjustment in the elevation information to compensate for the undulations of the geoid above and below the regular mathematical surface of the ellipsoid. The adjustment uses complex advanced geodetic techniques.

The Canadian SHORAN network connecting the sparsely populated northern coastal and island areas with the central part of the country and the North Atlantic HIRAN Network tying North America to Europe are examples of the application of the trilateration technique.

SHIRAN has been used in the interior of Brazil. E With this method, vertical measurements can be made at the same time horizontal angles are measured for triangulation. (adopted from http://www.ngs.noaa.gov/PUBS_LIB/Geodesy4Layman/TR80003B.HTM)

**II. Match words with their definitions:**

Barrier, azimuth, technique, loop, level, ellipsoid, elevation

1. ………. - a way of carrying out a particular task, especially the execution or performance of an artistic work or a scientific procedure;
2. ………. - the direction of a celestial object from the observer, expressed as the angular distance from the north or south point of the horizon to the point at which a vertical circle passing through the object intersects the horizon;
3. ………. - a three-dimensional figure symmetrical about each of three perpendicular axes, whose plane sections normal to one axis are circles and all the other plane sections are ellipses;
4. ………. - a height or distance from the ground or another stated or understood base;
5. ………. - the action or fact of raising or being raised to a higher or more important level, state, or position;
6. ………. - a circumstance or obstacle that keeps people or things apart or prevents communication or progress;
7. ………. - a length of thread, rope, or similar material, doubled or crossing itself, used as a fastening or handle

**III. Mark the following sentences True or False.**

1. Only distances are measured in trilateration.

2. If the traverse returns to the starting point or some other known position, it is an open traverse.
3. Reckoning navigation methods in geodesy involve the determination of an observer's position from observations of the moon, stars and satellites.
4. Vertical surveying is the process of determining heights-elevations above the mean sea level surface.
5. Trigonometric, differential and barometric leveling techniques turn in information of varying accuracy.
6. Differential leveling measures a vertical angle from a known distance with a theodolite and computing the elevation of the point.
7. In barometric leveling, differences in angles are determined by measuring the difference in atmospheric pressure at various elevations.

**III. Find words in the text similar in meaning.**

1. fulfill 2. spacious 3. space 4. use 5. dot 6. apparatus 7. precision 8. right-angled 9. vertical 10. compression

**IV. Translate the following sentences into English.**

1.Конечной целью построения геодезической сети (ГС) является определение координат геодезических пунктов.
2. Существуют методы построения ГС, выбор которых определяется условиями местности, требуемой точностью и экономической эффективностью.
3. Триангуляция - метод построения на местности ГС в виде треугольников, у которых измерены все углы и базисные выходные стороны. Длины остальных сторон вычисляют по тригонометрическим формулам, затем находят дирекционные углы (азимуты) сторон и определяют координаты.
4. Трилатерация - метод построения ГС в виде треугольников, у которых измерены длины сторон (расстояния между геодезическими пунктами), а углы между сторонами вычисляют.

5. Полигонометрия - метод построения ГС на местности в виде ломаных линий, называемых ходами, вершины которых закреплены геодезическими пунктами. Измеряются длины сторон хода и горизонтальные углы между ними.
6. Линейно-угловые построения, в которых сочетаются линейные и угловые измерения наиболее надежные.
7. Форма сети может быть различная, например четырехугольник, у которого измеряют все горизонтальные углы и две смежные стороны, а две другие стороны вычисляют.
8. Методы с использованием спутниковых технологий, в которых координаты пунктов определяются с помощью спутниковых систем - это российский Глонасс и американский GPS.
9. Эти методы имеет революционное научно-техническое значение по достигнутым результатам в точности, оперативности получения результатов, всепогодности и относительно невысокой стоимости работ по сравнению с традиционными методами восстановления и поддержания государственной геодезической основы на должном уровне.

## UNIT 3. GEODETIC SYSTEMS

**I. Read and translate the text. Write five Wh - questions to the text.**

### GEODETIC SYSTEMS

A datum is defined as any numerical or geometrical quantity or set of such quantities which serve as a reference or base for other quantities. In geodesy two types of datums must be considered: a horizontal datum which forms the basis for the computations of horizontal control surveys in which the curvature of the earth is considered, and a vertical datum to which elevations are referred. In other words, the coordinates for points in specific geodetic surveys and triangulation networks are computed from certain initial quantities (datums).

## Horizontal Geodetic Datums

A horizontal geodetic datum may consist of the longitude and latitude of an initial point (origin); an azimuth of a line (direction) to some other triangulation station; the parameters (radius and flattening) of the ellipsoid selected for the computations; and the geoid separation at the origin. A change in any of these quantities affects every point on the datum.

In areas of overlapping geodetic triangulation networks, each computed on a different datum, the coordinates of the points given with respect to one datum will differ from those given with respect to the other. The differences occur because of the different ellipsoids used and the probability that the centers of each datum's ellipsoid is oriented differently with respect to the earth's center. In addition, deflection errors in azimuth cause a relative rotation between the systems. Finally, a difference in the scale of horizontal control may result in a stretch in the corresponding lines of the geodetic nets.

## Datum Connection

There are three general methods by which horizontal datums can be connected. The first method is restricted to surveys of a limited scope and consists of systematic elimination of discrepancies between adjoining or overlapping triangulation networks. The second one is the gravimetric method of Physical Geodesy and the third – the methods of Satellite Geodesy. These methods are used to relate large geodetic systems to each other and/or to a world system. Both the 34 gravimetric and satellite methods produce necessary "connecting" parameters from reduction of their particular observational data.

## Vertical Datums

Just as horizontal surveys are referred to specific original conditions (datums), vertical surveys are also related to an initial quantity or datum. Elevations are referred to the geoid because the instruments used either for differential or trigonometric leveling are adjusted with the vertical axis coincident to the local vertical. As with horizontal datums, there are many discrepancies among vertical datums. There is never more than 2 meters variance between leveling nets based on different mean sea level datums; however, elevations in some areas are related to surfaces other than the geoid; and barometrically determined heights are usually relative.

In the European area, there are fewer vertical datum problems than in Asia and Africa. Extensive leveling work has been done in Europe and practically all of it has been referred to the same mean sea level surface.

However, in Asia and Africa the situation has been different. In places there is precise leveling information available based on mean sea level. In other areas the zero elevation is an assumed elevation which sometimes has no connection to any sea level surface.

China has been an extreme example of this situation where nearly all of the provinces have had an independent zero reference. There is very little reliable, recent, vertical data available for much of the area of Africa and Asia including China.

The mean sea level surface in the United States was determined using 21 tidal stations in this country and five in Canada. This vertical datum has been extended over most of the continent by first-order differential leveling. Concurrent with the new adjustment of the horizontal network, mentioned previously, is the readjustment of the vertical network. Countries of North and Central America are involved. In the conterminous United States 110,000 kilometers of the basic network are being releveled. (adpted from http://www.ngs.noaa.gov/PUBS_LIB/Geodesy4Layman/TR80003B.HTM)

**II. Mark the following sentences True or False.**

1. A horizontal datum is a datum to which elevations are referred and vertical one is a datum in which the curvature of the earth is considered. 2. There are some quantities which may affect every point on the datum. 3. The survey of the limited scope, the gravimetric method of Physical Geodesy and the methods of Satellite Geodesy are methods of horizontal datum. 4. There are no differences among vertical datums. 5. There are more vertical datum problems in Europe than in Asia. 6. China is an example of zero elevation which has no connection to the sea level surface. 7. The mean sea level surface in Canada was determined by 31 tidal stations.

**III. Translate the following text into English.**

1. Благодаря многочисленным измерениям и изучению статистики результатов, был обоснован постулат о форме Земли, как геоида – шара, сплюснутого в направлении полюсов. Учет этого обстоятельства позволил сделать картографию более точной, учесть изменения кривизны земной поверхности в зависимости от широты и долготы местности.

2. Для определения положения любой точки земной поверхности используют три координаты: широту, долготу и высоту над нулевым уровнем - уровнем моря.

3. В масштабе какой-либо одной страны нулевой уровень высот определяется на основании осредненных показателей многолетних замеров на нескольких водомерных постах.

4. Традиционно горизонтальные и вертикальная координаты рассматриваются порознь и исходные пункты устанавливаются для них отдельно.

5. Широко распространена, как метод съемки, геодезическая съемка, с помощью которой получают съемочный материал для геодезических карт или планов.

6. Геодезическая сеть любого вида представляет систему базисных точек или опорных пунктов земной поверхности, положение которых определено и зафиксировано в общей для них всех системе геодезических координат.

7. Любая сеть высотных опорных пунктов при выполнении геодезии земли строится методами геометрического или тригонометрического нивелирования.

## UNIT 4. PHYSICAL GEODESY

**I**. Read the text and answer the following questions.

1. What does Physical Geodesy study?
2. What types of gravity measurements exist?
3. What did scientists use to measure the gravity until the middle of the 20th century?
4. Why was the pendulum method superseded by the ballistic method?
5. What instruments were used for relative gravity measurements?
6. When was the first gravimeter developed?
7. What is drift?
8. What points are called base stations?

### PHYSICAL GEODESY
### (part 1)

Physical geodesy utilizes measurements and characteristics of the earth's gravity field as well as theories regarding this field to deduce the shape of the geoid and in combination with arc measurements, the earth's size. With sufficient information regarding the earth's gravity field, it is possible to determine geoid undulations, gravimetric deflections, and the earth's flattening.

In using the earth's gravity field to determine the shape of the geoid, the acceleration of gravity is measured at or near the surface of the earth. It might be interesting to compare the acceleration measured by the gravimetrist and the acceleration experienced in an airplane. In an airplane, the acceleration is simply called a G force and is measured by a G meter. A G factor of one is used to indicate the acceleration due to the attraction of the earth and is considered a neutral condition. The gravity unit used and measured in geodesy is much smaller. A G factor of one is approximately equal to one thousand gals, a unit named after Galileo. The still smaller unit used in geodesy is the milligal (mgal) or one-thousandth part of a gal. Thus, in geodesy we are dealing with variations in acceleration equal to one millionth of one G aircraft acceleration. The most accurate modern instruments permit measurement of acceleration changes of one hundred millionth part of the well known G factor or better.

## Gravity Measurements

Two distinctly different types of gravity measurements are made: absolute gravity measurements and relative gravity measurements. If the value of acceleration of gravity can be determined at the point of measurement directly from the data observed at that point, the gravity measurement is absolute. If only the differences in the value of the acceleration of gravity are measured between two or more points, the measurements are relative.

## Absolute measurement of gravity

Until the middle of the 20th century, virtually all absolute measurements of gravity were made using some type of pendulum apparatus. The most usual type of apparatus contained a number of pendulums that were swung in a vacuum.

By measuring the peroid of the pendulums, the acceleration of gravity could be computed. In 1818, Kater developed the so-called reversible pendulum that had knife edge pivots at both ends. These pendulums were flipped over (reversed) during the measurements and, using this procedure, a number of important error sources were eliminated. Still, there were numerous other problems and error sources associated with pendulum measurements of absolute gravity, and the results obtained were not sufficiently accurate to meet the needs of geodetic gravimetry.

Consequently, in recent years, the pendulum method has been superseded by the ballistic method which is based on timing freely falling bodies. The acceleration of gravity can be determined by measuring the time taken by a body to fall over a known distance.

**Relative measurement of gravity**

Solution of some of the problems of gravimetric geodesy requires knowledge of the acceleration of gravity at very many points distributed uniformly over the entire surface of the earth. Since absolute gravity measurements have been too complicated and time consuming and, until recently, could not be obtained with sufficient accuracy, relative gravity measurements have been used to establish the dense network of gravity measurements needed. The earliest relative gravity measurements were made with reversible pendulums. The most accurate relative 42 pendulums to be developed were the Gulf quartz pendulum and the Cambridge invar pendulum. These two instruments were used as late as 1969.

Modern relative gravity measurements are made with small, very portable, and easily used instruments known as gravimeters (gravity meters). Using gravimeters, highly accurate relative measurements can be made at a given site, known as a gravity station, in half-an-hour or less. Modern gravimeter-type instruments were first developed in the 1930's. There are two other important considerations when relative gravity measurements are made: drift and base station connections. Gravimeter drift is a phenomenon related to certain instrumental instabilities that cause the dial reading to change slowly with time even when the acceleration of gravity remains constant. Since relative gravity surveys can determine only differences in gravity from point to point, every relative gravity survey must include measurements at one or more reoccupiable points where acceleration of gravity is known. Such points are called base stations. Then all gravity difference measurements are computed with respect to the known gravity value at the base station. Hence, tying a relative gravity survey to a base station establishes the "gravity datum" of that survey. The earliest "gravity datum" was the so-called Potsdam System. The Potsdam system, however, was found to be in error and, in 1971, was replaced by the International Gravity Standardization Net 1971 (IGSN71).

(adopted from http://www.ngs.noaa.gov/PUBS_LIB/Geodesy4Layman/TR80003C.HTM)

**II. Mark the following sentences True or False.**

1. Having information about the earth's gravity field, you can determine geoid undulations, gravimetric deflections and the earth's flattening.
2. In geodesy it is dealt with variations in acceleration equal to one thousandth of one G aircraft acceleration.
3. Kater developed a pendulum but measurements and results were not rather accurate.
4. Absolute gravity measurements were simple but time consuming.
5. Reversible pendulums are small, portable and easily used instruments.
6. Gravimeter-type instruments were first developed at the beginning of the 20th century.
7. Base stations are reoccupiable points where acceleration of gravity is known.

8. The Potsdam System was replaced by the IGSN in 1977.

**III. Match words with their definitions.**

Point, geoid, instability, gravity, apparatus, pivot, instrument acceleration

1. ………. - a hypothetical solid figure whose surface corresponds to mean sea level and its imagined extension under (or over) land areas;
2. ………. - the force that attracts a body towards the centre of the earth, or towards any other physical body having mass;
3. ………. - the rate of change of velocity per unit of time;
4. ………. - a tool or implement, especially one for precision work;
5. ………. - tendency to unpredictable behaviour or erratic changes of mood;
6. ………. - the technical equipment or machinery needed for a particular activity or purpose;
7. ………. - the central point, pin, or shaft on which a mechanism turns or oscillates;
8. ………. - a particular spot, place, or position in an area or on a map, object, or surface.

**IV. Translate the following sentences into English.**

1. Относительные определения силы тяжести производятся маятниковыми приборами.
2. Наиболее распространенный прибор для измерения силы тяжести – гравиметр, используемый для относительных измерений, т.е. разности значений силы тяжести в двух пунктах.
3. Существует специальная гравиметрическая аппаратура для измерений силы тяжести с движущихся объектов (подводных и надводных кораблей, самолѐтов).
4. Для проведения абсолютных измерений силы тяжести требуется большое количество вспомогательного оборудования, поэтому их нецелесообразно проводить при обычных геодезических съемках.
5. Международная гравиметрическая стандартная сеть по состоянию на 1971 включала 10 гравиметрических станций для абсолютных измерений и 1854 пункта для относительных измерений силы тяжести.
6. Хотя статические гравиметры позволяют получить наиболее точные значения, их использование в полевых условиях требует значительных затрат труда и времени.
7. Определения силы тяжести производятся относительным методом, путем измерения при помощи гравиметров и маятниковых приборов разности силы тяжести в изучаемых и опорных пунктах.
8. Сеть опорных гравиметрических пунктов на всей Земле связана в конечном итоге с пунктом в Потсдаме, где оборотными маятниками в начале 20 века было определено абсолютное значение ускорения силы тяжести.
9. Наиболее точно абсолютное значение силы тяжести определяется из опытов со свободным падением тел в вакуумной камере.

**VI. Read the text and answer the following questions.**

1. When did first gravimeters on ships appear?
2. What instruments were used on surface ships?
3. What is a problem with ocean surface measurements?
4. What systems are used near the shore and in the deep ocean?

5. What problems are there with gravity measurements in the air?
6. What is gravity anomaly?
7. What is the most common type of gravity anomaly?
8. Who developed formulas for computing the gravimetric deflection of the vertical?
9. What does the effectiveness of the gravimetric method depend on?

## PHYSICAL GEODESY
## (part 2)

### Gravity measurement at sea

The earliest measurements at sea were made by F.A. Vening Meinesz who, in 1927, installed a pendulum apparatus in a submarine. The submarine pendulum gravity measurements of Vening Meinesz are mainly of historical interest today. The first gravimeters installed in surface ships appeared during the 1950's. These early ocean surface gravity measurements were only of modest accuracy and, again, now are mainly of historical value. Reasonably accurate measurements from gravimeters on surface ships date only from the late 1960's. Instruments used include LaCoste  Romberg S Meter, Askania Meter, Bell Meter, and the Vibrating String Gravimeter. All of these meters are compensated to minimize the effects of oscillatory motion of the ship due to ocean surface waves. The effects are also eliminated or averaged out by computational techniques. A big problem with ocean surface measurements is that the forward motion of the ship adds a centrifugal reaction component to measured gravity which must be eliminated by the so-called Eotvos correction. Therefore, the ship's velocity and heading, as well as the ship's position, must be known accurately. Near shore, shore based electronic positioning/navigation systems (such as LORAN) are used. In the deep ocean, satellite navigation and inertial systems must be used.

### Gravity measurement in the air

Problems in airborne gravity measurements are similar to those encountered for surface ships. The position, velocity, and heading of the aircraft must be known accurately. Because of the higher aircraft speeds, the Eotvos correction is much larger for airborne measurements than for surface ship measurements. It also is very difficult to compensate for spurious aircraft accelerations. In addition, reduction of the gravity value from aircraft altitude to an equivalent surface value is a problem that has not yet been solved satisfactorily.

## Gravity Anomalies

Gravity measurements provide values for the acceleration of gravity at points located on the physical surface of the earth. Before these measurements can be used for most geodetic purposes, they must be converted into gravity anomalies. 49 A gravity anomaly is the difference between a gravity measurement that has been reduced to sea level and normal gravity. Normal gravity, used to compute gravity anomalies, is a theoretical value representing the acceleration of gravity that would be generated by a uniform ellipsoidal earth. By assuming the earth to be a regular surface without mountains or oceans, having no variations in rock densities or in the thickness of the crust, a theoretical value of gravity can be computed for any point by a simple mathematical formula. The most common type of gravity anomaly used for geodetic applications is the so-called free-air gravity anomaly.

## Undulation and Deflections by the Gravimetric Method

The method providing the basis from which the undulations of the geoid may be determined from gravity data was published in 1849 by a British scientist, Sir George Gabriel Stokes. However, the lack of observed gravity data prevented its application until recent years. In 1928, the Dutch scientist, Vening Meinesz, developed the formulas by which the gravimetric deflection of the vertical can be computed. The computation of the undulations of the geoid and the deflections of the vertical require extensive gravity observations. The areas immediately surrounding the computation point require a dense coverage of gravity observations and detailed data must be obtained out to distances of about 500 miles. A less dense network is required for the remaining portion of the earth. While the observational requirements for these computations appear enormous, the results well justify the necessary survey work. Effective use of the gravimetric method is dependent only on the availability of anomalies in sufficient quantity to achieve the accuracy desired. Successful use of Stoke's integral and Vening-Meinesz formulas depends on a good knowledge of gravity anomalies in the immediate vicinity of the point under consideration and a general knowledge of anomalies for the entire earth.

There are many large regions on the continents where gravity measurements are lacking or available only in small quantities. Gravity data for ocean areas has always been sparse, however, Satellite Altimetry has overcome this deficiency. In regions where an insufficient number of gravity measurements exists, some other approach must be used to obtain or predict the mean gravity anomalies for the areas.

Correlations exist between variations in the gravity anomaly field and corresponding variations in geological, crustal, and upper mantle structure, regional and local topography and various other types of related geophysical data. In many areas where gravity information is sparse or missing, geological and geophysical data is available. Therefore, the various prediction methods take into account the actual geological and geophysical cause of gravity anomalies to predict the magnitude of the anomalies. (adopted from http://www.ngs.noaa.gov/PUBS_LIB/Geodesy4Layman/TR80003C.HTM)

**VII. Mark the following sentences True or False.**

1. V. Meinesz used submarines for marine gravity surveys.
2. Early ocean surface gravity measurements were of precise accuracy.
3. Problems with gravity measurements in the air and in the sea are different.
4. The problem of reduction of gravity value from aircraft altitude to an equivalent surface is not solved.
5. Before being used for geodetic purposes, gravity measurements are converted into gravity anomalies.
6. In 1939 a British scientist published his method of determining the undulations of the geoid from gravity data.
7. Extensive gravity observations are necessary for computing the undulations of the geoid and the deflection of the vertical.
8. Geological and geophysical data is not available in areas where gravity information is sparse or missing.

## SUPPLEMENTARY READING

### GPS Network Design

In recent years, satellite methods such as the Global Positioning System (GPS) have gradually been replacing traditional procedures for conducting precise horizontal control surveys. In fact, GPS not only yields horizontal positions, but it gives ellipsoidal heights as well. Thus, GPS provides three-dimensional surveys.

Upon development of the Global Positioning System (GPS), it became very attractive for surveyors due to its fast, accurate and economical results. GPS also can be operated in all weather and 24 hours a day, while still giving precise surveying measurements.

Nowadays, with increasing technological developments, GPS networks have taken place of terrestrial networks.

Optimal design of geodetic GPS networks is an essential part of most geodesy related projects. Whether or not the datum and point locations of a network are known, the process of determining the optimal baseline configuration and their optimal weights—the ―second order design problem‖ (SOD)—with respect to the selected design criteria can be achieved by optimizing the observational plan. The scalar design criteria can only satisfy limited demands for a network, however. Thus, criterion matrices are mostly used; these can be defined as the computed variance covariance matrix in the design stage that meets many of the accuracy demands. Analytical approximations of the criterion matrices are an effective method of reaching objective functions formulated with criterion matrices.

Theoretically, the best precision and reliability of the relative positions of a GPS network can be obtained if all visible satellites are tracked as long as possible and all possible baselines in the network are measured. Due to the limitations of time and expense, however, that will rarely happen in practice, and therefore an optimum survey design has to be made in order to achieve some prescribed design criteria while minimizing effort.

In the present study, the optimization procedure gives the optimal observational weights, which can be grouped into significant and zero or insignificant weights. The significant weights, some of which may be smaller than the initial weights, are then replaced by their corresponding initial weights. Baselines that obtain a zero or insignificant weight represent those that should be deleted from the final observing plan.

There are two methods for design of a GPS network, classical methods and intelligent optimization techniques. Classical methods include the trial and error 82 method and the analytical method, while intelligent optimization techniques include global optimization techniques and local optimization techniques. Recently, some global optimization methods such as the Particle Swarm

Optimization (PSO) algorithm or genetic algorithms have begun to be used in geodetic science.

The PSO method was originally intended for simulating the social behavior of flocks of birds, but the algorithm was simplified and the realization was made that the agents, here typically called particles, were actually performing black-box optimization. In PSO the population of particles is typically called a swarm. In the PSO method, particles are initially placed at random positions in the search-space, moving in randomly defined directions. The direction of a particle is then gradually changed so it will start to move in the direction of the best previous positions of itself and its peers, searching in their vicinity and potentially discovering even better positions.

In general, there are several techniques that can be applied for solving the problem of determining the maximum or minimum value of a function. The main kinds of these techniques are classical optimization techniques and intelligent optimization techniques. The classical optimization techniques are useful for finding the optimum solution or unconstrained maxima or minima of continuous and differentiable functions.

Classical techniques are not exempt from problems. For instance, there may be either no consistent solution, or a solution wherein the proposed network contains many observations which are assigned a weight of zero, which makes these sites disappear from the observation plan and drastically diminishes network redundancy. Many new attempts and applications have been derived for network design problems such as intelligent optimization techniques. The successful performance of these intelligent optimization techniques has also led to their application in many other problems in geodesy and geodynamics. Intelligent optimization techniques represent a new approach to addressing complex problems with uncertainties. Intelligent systems are defined by such attributes as having a high degree of autonomy, being capable of reasoning under uncertainty, having higher performance in a goal seeking manner, working at a high level of abstraction, being able to fuse data from a multitude of sensors, learning and adapting to a heterogeneous environment, and so on. Intelligent optimization techniques can be divided into two categories: local and global optimization.

A local maximum is a candidate solution that has a higher value from the objective function than any candidate solution in a particular region of the search space. Many optimization algorithms are only designed to find the local maximum, ignoring both other local maxima and the global maximum. Recently, new solutions for optimization problems for geodetic networks have emerged which are intelligent (global) optimization techniques. These include Genetic Algorithms (GAs), Particle Swarm Optimization (PSO) and Simulated Annealing (SA).

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