

# CHAPTER 1

## Overview of Surveying

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Surveyors determine horizontal and vertical distances between objects, measure angles between lines, determine the direction of lines, and establish points of predetermined angular and linear measurements. Once the field measurements are complete, surveyors use these to compute the data into a final report used for positioning by field artillery, air defense artillery, aviation, intelligence, communications, or construction control points.

### Section I

## MISSIONS, CLASSIFICATIONS, AND NETWORKS

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### MISSIONS

The missions of the military topographic surveyor are —

- Support deployable weapons systems (nuclear and nonnuclear) with position and azimuth.
- Support aviation with position, azimuth, and elevation.
- Support intelligence with precise position and azimuth.
- Support communications with line-of-sight profiles, position, and 360-degree visibility studies,
- Establish and extend basic control with field surveys.
- Forward survey data and station description cards to Defense Mapping Agency, the organization's survey information center (SIC), and colocated terrain analysis teams upon request,

These missions are defined in *AR 115-11*, in *FM 5-105*, unit table(s) of organization and equipment (TOE), and by directives from higher headquarters.

### GEODETIC AND PLANE SURVEYS

The actual shape of the solid mass of the earth is referred to as the topography. The geoid is defined as the surface of the earth's gravity (attraction and rotation) which, on the average, coincides with mean sea level in the open undisturbed ocean. The spheroid (an ellipsoid of revolution), appears as a figure flattened at the poles and bulging at the equator. It can be described using a mathematical formula that approximately defines a part of the surface of the geoid. However, because of the great variations in topography, many different spheroids exist. Because the earth's surface is irregular and pieces of mathematical computations are unreliable, the surveys conducted depend on the purpose or level of accuracy required.

In plane surveys all points are referenced to a flat plane, with curvature wholly or mostly ignored. In geodetic surveys, all established points are referenced to the curved surface of a spheroid and in all computations the effect of curvature is computed,

### CLASSIFICATIONS

#### Technical Classifications

Geodetic surveys take into account the size and shape of the earth. Since the stations in geodetic surveys are routinely spaced over extended distances, more precise instruments and procedures are required than for plane surveys. All observations are made on the actual curved surface of the earth and this curvature is corrected through computations. The computational methods used in geodetic survey are discussed in *TM 5-237*.

Plane surveys ignore the actual shape of the earth and apply the principles of plane geometry and trigonometry. When the survey is less than 250 square kilometers in area and less accuracy is needed, curvature can be ignored. These surveys are treated as if the measurements were made on a flat plane, with all lines being straight. Most localized construction projects and boundary projects are plane surveys. The more extensive highway/railroad construction projects are generally plane surveys. The computational methods used in plane surveys are described in appropriate chapters of *FM 5-233* and *TM 5-237*.

#### Functional Classifications

**Construction surveys.** These surveys provide data, planning, and cost estimating essential to locate or lay out engineering works and are recorded on engineer maps. These surveys normally use plane surveying techniques. The methods, techniques, and procedures

used by the military construction surveyor are detailed in *FM 5-233*.

#### **Artillery surveys.**

*Field artillery* fire-control surveys are conducted to determine the relative positions of weapons systems to targets, but do not require the accuracy of geodetic surveying procedures despite the relatively large areas and long distances. The requirements, methods, and procedures used by the military field artillery surveyor are detailed in *FM 6-2*.

*Air defense artillery* weapons systems require the accuracy obtainable only with geodetic survey techniques.

**Basic control (geodetic) surveys.** These are surveys which provide horizontal and/or vertical positions of points which supplementary surveys may originate from and can be adjusted to. The basic control survey of the United States provides geographic positions and plane coordinates of triangulation/traverse stations and the elevations or bench marks. This information is used as the basis for the control of the topographic survey of the United States; for the control of many state, city, and private surveys; and for hydrographic surveys of the coastal waters. Techniques and procedures used by the military geodetic surveyor are discussed in this manual.

**Astronomic surveys.** The celestial determination of latitude and longitude separations are calculated by computing distances corresponding to measured angular displacements along the reference spheroids.

**Satellite surveys.** These surveys are conducted using artificial earth satellites for long-line surveys. Since distances between stations may vary from 100 to 1,500 miles, doppler transit satellites and the global positioning system (GPS) geocentric satellites are typical.

#### **Special surveys.**

*Hydrographic surveys.* These are surveys made on large bodies of water to determine channel depths for navigation and locations of rocks, sandbars, lights, and buoys. In the case of rivers, these surveys are made to support flood control projects, power development, navigation, water supply, and water storage.

*Field classification and inspection surveys.* These surveys help identify features not normally revealed using a compiler. Examples include political boundary lines, place names, road classifications, and buildings

obscured by trees. They also help clarify aerial photographs using comparisons with actual ground conditions.

*Gravity surveys.* These surveys result in the intensity of the gravitational forces at or near the earth's surface. Gravity observations may be either absolute or relative. Absolute gravity is the gravity at a specific point, while relative gravity reflects gravitational variations from point to point.

*Land surveys.* This is the process of locating the boundaries and areas of tracts of land.

*Inertial surveys.* These surveys determine relative positions and azimuths. The position and azimuth determination system (PADS) is now being used extensively to support artillery survey requirements.

*Airfield surveys.* These surveys are made to determine any combination of the following:

- Location of obstacles within 10 nautical miles of the airfield center.
- Dimensions of runways and taxiways, heights of flight towers, and navigational aids.
- Safe approach angles to runways and minimum safe glide angle.
- Elevation of barometer on the airfield.
- Positions and azimuths of points designated for inertial navigational systems (INS) checkpoints.
- Requirements of the Federal Aviation Administration (FAA), United States Army Aeronautical Services Office (USAASO), or equivalent military activity.
- Incidents of a military aircraft crash or disaster.

### **SURVEY NETWORKS**

Horizontal and vertical survey control within a country is usually established by a network of control areas. These areas are all referenced to a single datum and are related in position or elevation to each other. The networks are called basic, supplementary, and auxiliary. Currently, all horizontal networks in the United States are referenced to the *North American 1927 Datum (NAD 1927)* and *North American 1984 Datum (NAD 84 and WGS 83 are the same)* with coordinates currently being published in both data.

Mean Sea Level 1929 is being used for vertical control points. Within the continental United States, the following definitions are used.

#### **Basic**

**Basic horizontal control networks.** These networks are usually established by first-order geodetic

triangulation, precise electronic traverse, or satellite translocation. The lines of the basic network are typically spaced approximately 96 kilometers apart throughout a country.

**Basic vertical control networks.** These networks are established by first-order differential leveling in areas spaced from 90 to 160 kilometers apart throughout the country. Permanent bench marks are spaced approximately 3 kilometers apart on these lines.

#### Supplementary

**Supplementary horizontal control network.** This network is usually established by second-order survey procedures. The supplementary nets are used to fill in the areas between the basic control lines. Ultimately, a station of either the basic or supplementary networks will be spaced at intervals of between 6 to 16 kilometers across the country.

**Supplementary vertical control network.** This network is established by second-order differential level-

ing. These lines are run within the basic control arcs to provide a planned control line spacing of about 10 kilometers. Permanent bench marks are emplaced about 2 kilometers apart on these lines.

#### Auxiliary

**Horizontal auxiliary (or additional) control networks.** These networks are usually established by second- or third-order survey procedures. The networks are established to provide localized control to be used by surveyors for artillery control, construction engineering surveys, mapping projects, or other positioning requirements. Additionally, as more states require geodetic accuracies, these networks will be used by states and other agencies for boundary and property surveys.

**Vertical auxiliary control networks.** These networks are established by third-order differential leveling and are used to provide localized vertical control. This control is also used to support artillery construction and engineering projects.

## Section II FIELD WORK

Survey field work consists of making observations and measurements and recording the data. The surveyors must also overcome many factors that combine to affect working conditions.

### OBSERVATION AND MEASUREMENT FUNCTIONS

Observations and measurements are generally made for the following reasons:

- **Observing Distances and/or Directions (Angles)**
- To establish triangulation and traverse stations for basic, supplementary, and auxiliary control networks.
- To establish gun and target positions for artillery batteries.
- To establish horizontal control to support PADS.
- To establish point and lines of reference for locating detail such as boundary lines, roads, buildings, fences, rivers, bridges, and other existing features.
- To stake out or locate roads, buildings, landing strips, pipelines, and other construction projects.
- To establish lines parallel to or at right angles to other lines; or to determine the area of tracts of land, measure inaccessible distances, or extend straight lines beyond obstacles.
- To establish picture points for data bases.

- To do any other work which may require use of geometric or trigonometric principles.

#### Observing Differences in Elevations

- To establish bench marks for basic, supplementary, or auxiliary vertical control networks.
- To determine differences in elevation of terrain along a selected line for plotting projects and computing grade lines.
- To stake out grades, cuts, and fills for earthmoving and other construction projects.
- For trigonometric elevations of triangulation and traverse stations for control nets and mapping projects.
- For gun and target position for field artillery batteries.

#### Recording Field Notes

Field notes are made to provide a permanent record of the field work. These notes take the form of-

- Field recording booklets.
- Single sheet recording forms.
- Magnetic tapes for automatic data recording.
- Plane table sheets.
- Land survey plans.
- Property plans.
- Recovery and station description cards.

- Control diagrams showing relative location, methods, and type of control established and/or recovered.

### **FACTORS AFFECTING FIELD WORK**

The field surveyor must be constantly alert to the various conditions. Weather, terrain, personnel, equipment, purpose, required accuracy, systematic procedures, rates of progress (speed), and the enemy situation all influence the work.

#### **Weather and Terrain**

Weather and terrain can adversely affect field surveys. The effectiveness of optical and electro-optical instruments can be severely reduced by fog, mist, smog, or ground haze. Swamps and flood plains under high water can impede taping or leveling operations. Distances measured over open water and fields of flat unbroken terrain or near high-power transmission lines can create ambiguities when using microwave equipment. Maximum length measurements obtained by electro-optical distance measuring equipment (DME) can be reduced in bright sunlight. Good reconnaissance and proper planning can alert the field parties of the best times and methods to use.

#### **Personnel**

The level of training and experience of the personnel also affect field work. The rate of progress often varies in proportion to the personnel experience level.

#### **Equipment**

Modern, well-maintained equipment can often increase the rate of progress. Even older equipment, if properly maintained or adjusted, will yield accurate results. Repairing or replacing broken instruments or parts is sometimes responsible for slowing down or stopping a field survey. Therefore, equipment reliability must be considered when setting completion dates.

#### **Purpose and Type of Survey**

The purpose and type of survey determine the accuracy requirements. First-order triangulation, traverse, or leveling for the control networks must have high accuracy standards. At the other extreme, cuts and fills for a highway have much lower standards. In some surveys, distances to inaccessible points must be determined. Highly accurate distance and angle measurements are required so that these values, when used in trigonometric formulas, will yield acceptable results.

#### **Required Accuracy**

Accuracy requirements will dictate the equipment and procedures selected. For instance, comparatively rough procedures can be used in plane table operations, but control network leveling requires much more precise and expensive equipment as well as extensive, time-consuming procedures.

#### **Errors**

All measurements contain some error. The errors classified as systematic and accidental are the most common uncontrollable errors. Besides errors, measurements are susceptible to mistakes or blunders. These arise from misunderstanding the problem, poor judgment, confusion, or carelessness. The overall effect of mistakes and blunders can be greatly reduced by establishing a systematic procedure. The system will be an advantage in all phases of the survey and can result in great time savings.

#### **Rates of Progress (Speed)**

Rates of progress vary depending on experience and repetition. As skill and confidence increase, so will speed. Proper preparation and planning will reduce duplication of effort and increase efficiency.

#### **Enemy Situation**

A hostile environment often forces a schedule adjustment. Night work will require greater speed, fewer lights, and increased security. Adding security forces increases the number of vehicles and personnel which, in turn, involves reduced efficiency, thus retarding even the most ambitious time schedule.

#### **FIELD NOTES**

Even the best field survey is of little value if the notes are not complete and clear. The field notes are the only record that is left after the survey party leaves the field site. The surveyor's notes must contain a complete record of all measurements or observations made during the survey. When necessary, sketches, diagrams, and narrations should be made to clarify notes. Write overs, erasing, use of ink eraser, correcting tape, and whiteout are strictly forbidden. These actions, when prohibited by the unit survey standing operating procedures (SOP), are cause for punishment under the Uniform Code of Military Justice. Recording errors are to be lined out, initialed by the recorder and the correct new reading entered on the recording form.

### Recording Qualities

Good field notes share these qualities:

**Neatness.** The lettering conforms to the gothic style portrayed in *FM 5-553*. All entries are formatted according to local SOPs.

**Legibility.** Only one interpretation should be possible. Decimal points and commas must be clear and distinct.

**Completeness.** All entries are completed and all resolved data are finished according to local SOPs.

**Done in field.** All recording is done on the correct specified forms entirely in the field. Notes are never recorded on scrap paper and transcribed to a field recording form. If performing an underground survey, obtain and use a covered clipboard to protect the notes.

**No erasures.** All field work will be done in black or blue-black ink suitable for photocopying. The only exception is the field sheet of a plane table survey.

**No write overs.** Field notes show what happened in the field. If a number is changed, the correct procedure is to make a single slanted line through the incorrect number. The individual making the corrections inserts the correct number directly above or next to the corrected value, creating the new entry and initialing the change. A note will be entered in the Remarks column stating why the number was changed.

**True picture.** The field notes accurately describe the field experience. Sketches, diagrams, and notes reduce or eliminate questions.

### Organizing Survey Notes

Survey notes are usually kept in a field notebook, or on individual recording forms, or on tape if an automatic data collector is used. Regardless of the type used, the following information must appear:

- 1 Instruction for return of the book or notes, if they should be lost. Usually, it will be returned to the commander of the particular unit.
- 2 Index of field notes contained in the book and cross-referenced to additional books or binders.
- 3 List of party personnel, their duties, and the dates on the project (from - to).
- 4 List of instruments used, to include types, serial numbers, calibration date, constant values, and dates used.
- 5 A generalized sketch and description of the project.
- 6 The actual survey notes on each page containing

data. The heading must be filled out, to include –

- Station names, including establishing agency and date.
- Date of the survey.
- Personnel names and survey duty (instrument operator, notekeeper).
- Instruments used and serial numbers.
- Weather data.
- The actual observed data, to include all required reductions.
- Pertinent notes, as required.
- The observer's initials, indicating that the observer has checked all entries and ensured they are correct. The observer's initials will be at the bottom right corner of the recording form.

Loose-leaf sheets should be serially numbered to ensure that all sheets are kept and turned in. The cassette tapes must be clearly marked for return to the unit, and require special handling.

### Types of Recording

Field note recording takes three general forms: tabulation, sketches, and descriptions.

**Tabulation.** Numerical data is recorded in columns following a prescribed format, depending on the type of operation, instrument used, and specifications for the type of survey.

**Sketches.** Sketches add much to the clarity of field notes and should be used liberally. They may be drawn to scale, as in plane table surveys, or they can be drawn to an approximate scale, as in control cards. If an exaggerated scale is needed to show detail, the use of such a scale is recommended. Measurements should be added directly on the sketch or keyed in some way to avoid confusion. Sketches require the same qualities as all other field notes.

**Descriptions.** Tabulations with or without sketches can also be supplemented with narrative descriptions. The description may only consist of one or two words or it may be very detailed. It must be remembered that survey notes become a part of historic records. A brief description entered at the time of the survey may be important and helpful at some time in the future.

### Abbreviations and Symbols

It is strongly recommended that standard abbreviations, signs, and symbols be used in all survey notes. These abbreviations, signs, and symbols must be in accordance with current guidelines in such publications as *AR 310-50*, *FM 21-31*, and *FM 101-5-1*. If there is

any doubt as to the meaning or interpretation of a symbol or abbreviation, the words must be spelled out.

### **Corrections**

Field notes are considered legal documents, since they can and have been used in court proceedings. As such, **NO ERASURES OR WRITE OVERS ARE PERMITTED**. Individual numbers are corrected as stated in Recording Qualities, page 1-5. No position will be voided or rejected in the field except in the case of disturbing the instrument or target or observing the wrong target. In either case, the position should be **reobserved**, stating in the Remarks section the location of the reobserved data.

### **Waterproofing**

Every effort must be made to protect field notes. Even in high humidity or rain, field notes can be waterproofed by spraying a thin coat of clear acrylic plastic on the field record. If applied before the recording, the paper will be waterproof but still allow recording with ordinary writing instruments. The field notes can be sprayed again after use, and the plastic fixes the writing and prevents water damage to the records. One such spray is *Krycor, workable FIXA T-IF #1306*; however, many other sprays are available and any of them may be used.

### **SURVEY COMMUNICATIONS**

Survey party members may find themselves separated. The ability to communicate with each other may mean the difference between successfully completing a section of work or not. Even at relatively short distances (as in taping, plane table, or leveling opera-

tions), background noises can obscure direct voice contact. At longer distances such as in electronic distance measuring equipment (EDME) or direction measurement operations, effective direct voice contact is impossible. Therefore, some other types of communications are required.

### **Hand Signals**

Communication over short distances can effectively be accomplished using hand and arm signals such as are shown in Figure 1-1. All party members must know the signals and their exact meaning. Each signal is given while facing the person being signaled.

### **Voice Communications**

On long lines where hand signals are impossible, the radio must be used. Each theater of operations or Army command has published communications-electronics operation instructions (CEOI), with which the user units must comply. Only frequencies obtained through the local signal officer may be used. All personnel using radios must be familiar with the CEOI and the unit's communications SOP before using a radio. All radio communications must be kept as short and secure as possible.

### **Mirrors and Lights**

Mirrors and lights can also be used for communication. The emergency signal mirror can use the sun as a light source and is a fairly accurate sighting device. Morse code or other prearranged signals can be used to effectively communicate during the day. At night, the same signals can be used with a 5-inch or other light.

## **Section III OFFICE WORK**

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Surveying also consists of converting the field measurements into a more usable form. The conversions or computations maybe required immediately to continue the field work. At other times, they must be held until a series of field measurements is completed. This is called office work, even though some of the operations may be performed in the field during lapses between measurements.

### **OPERATIONS**

Some office functions use special equipment (slide rules, conversion tables, calculators, computers, or drafting equipment) or require extensive references and working areas.

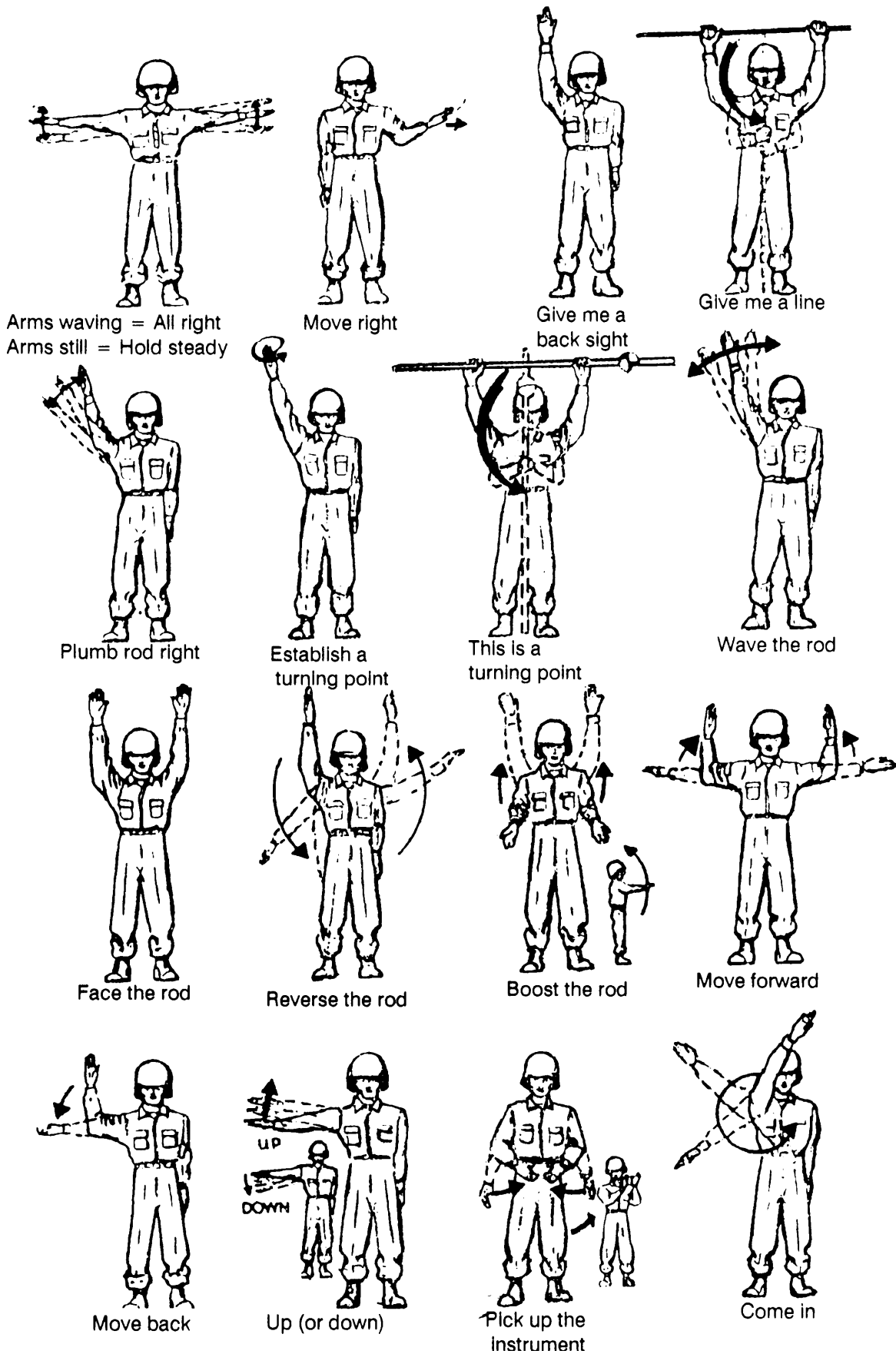
### **Working Up Field Notes**

During survey operations, many field measurements require some form of arithmetical computation. It may be a simple addition of several full (tape) lengths and a partial tape length to record a total distance between two points. It maybe adding or subtracting differences in elevation to determine height of instrument or elevation during leveling, or it maybe checking angles to see that the allowable error is not exceeded.

### **Computing**

Office computing converts distances, angles, and rod readings into a more usable form. The measurements may end up as a computed volume of dirt to be moved for a highway cut or fill, an area of land needed

Figure 1-1. Hand and arm signals



for a construction project, or an adjusted position of some point or mark from which other measurements can be made.

**Distances.** Distances measured by tape are measured in short horizontal distances. For higher accuracy, corrections to taped distances must be applied for temperature, tension, or sag of the tape. The desired result is the horizontal distance between two points. In electronic distance measuring (infrared and microwave), the distance is almost always on a slope and has to be corrected for temperature and barometric pressure, then reduced to corrected horizontal distance.

**Azimuths and bearings.** In many operations, the observed angles are converted into directions of a line from north (azimuths) or a north-south line (bearings).

**Relative positions.** The distance and direction of a line between two points determines the position of one point relative to the other point. If the direction is given as a bearing or azimuth, a trigonometric formula using the sine or cosine of the angle, multiplied by the distance, will result in a coordinate difference between the two points.

### Adjusting

Some survey techniques are not complete until one more procedure is performed.

**Definition.** Adjusting is the determination and application of corrections to data. Adjustment causes the data to be consistent within themselves and to a given set of references. Small errors which are not apparent during individual measurements can accumulate to a sizable amount. For example, assume that 100 measurements were made to the nearest unit and required determining which unit mark is closer to the actual measurement. At the end of the course, an error of + 4 units resulted. Adjusting the result means reducing each measurement by 0.04 unit. Since the measurements were only read to the nearest unit, a single adjustment would not be measurable at any point and the adjusted result would be correct. Some of the more precise surveys require least square adjustments.

**Traverse.** Traverse is the measurement of lengths and determination of directions of a series of lines between known points and establishes the coordinates of the intermediate points. When computed, the accumulated closing error shows up as a position displacement

of a known point. The displacement is corrected and distributed among the intermediate (traverse) points.

**Triangulation.** Adjusting triangulation consists of adjusting the three angles of each triangle to equal 180 degrees, then computing the lengths of the unknown sides of the triangle, using a measured or computed side (baseline). The newly computed sides become the known distance values of adjoining triangles. Computing continues through the triangulation net until a second baseline is reached. The closure (difference between the measured baseline distance and the distance as computed through the triangles) must be within prescribed limits. The amount of closure is then adjusted back through the net, affecting the positions of the stations.

**Elevations.** Depending on the purpose, the elevations on some level lines are computed as the measurements are taken. When the line is closed, the difference in elevation between the measured and the known elevation is adjusted over all the stations in the line. In higher order leveling, only the differences in elevation are recorded during the measuring, with all adjusting done at the completion of the line. The error is then distributed among the various sections of the line.

## PROCEDURES

### Establishing Records

Office computations reduce the field notes to a tabular or graphic form. This becomes a permanent record and is stored for further use or subsequent operations. Many standardized forms are available and cover most procedures. These forms are recommended when available, but the surveyor is not limited to these. As long as the sheets are clearly identified and bound as a set, they may be acceptable. Normally, all field notes will be abstracted and the field notes filed separately. The abstracts will be bound along with all computing forms into a single binder or folder, and maintained on file for further reference. All pages, either abstracts or computing forms, will bear the name and date of the person performing the work. The pages will also bear the name and date of at least one person who has checked that page. At no time will any of these records be disposed of or destroyed.

### Checking

Surveying is a series of checks. The field notes should be checked by the observer, the recorder, and the party chief before the notes are turned in for office work. Prior to computing, the assigned person should check the notes again. Most mathematical problems

can be solved by more than one acceptable method. In checking a set of computations, a method which differs from the original computation may be desirable. An inverse solution, starting with the computed values and solving for the field data is one possibility. A graphic solution may be used. Each step that cannot be checked by any other means must be checked by a totally independent recomputation by another individual. Any errors or mistakes found must be resolved and rechecked before the computation is accepted.