Chapter 2
Photogrammetric Accuracy Standards and Classifications

2-1. General

This chapter presents USACE photogrammetric mapping standards that have been established to specify the quality of the spatial data product (i.e., map) to be produced. These standards are drawn largely from recognized industry standards.

a. Minimum accuracy standards. This chapter sets forth the accuracy standards to be used in USACE for photogrammetrically derived maps and related spatial data products. Minimum requirements to meet these accuracy standards are given for critical aspects of the photogrammetric mapping and mensuration process, such as maximum flight altitudes, maximum photo enlargement ratios, C-Factor ratio limitations, and aerotriangulation adjustment criteria.

b. Target scales. Mapping accuracy standards are associated with the final development scale of the map—both the horizontal "target" scale and vertical relief components. The use of CADD equipment allows the ready separation of planimetric features and topographic elevations to various layers, and depiction at any scale. Problems arise when target scales are increased beyond their original values, or when so-called "rubber sheeting" is performed. *It is therefore critical that these spatial data layers contain descriptor information identifying the original source target scale and designed accuracy.*

c. Mapping requirements. The specified accuracy of a map product shall be sufficient to assure that the map can be reliably used for the purpose intended, whether this purpose is an immediate or a future use. However, the accuracy of a map shall not surpass that required for its intended functional use. Specifying map accuracies in excess of those required for project design, construction, or condition reports is all too often performed; results in increased costs to USACE, local sponsors, or installations; and may delay project completion. It is absolutely essential that mapping accuracy requirements originate from the functional and realistic accuracy requirements of the project. General guidance on project-specific accuracy requirements is contained in this and later chapters.

d. Chapter precedence. The standards set forth in this chapter shall have precedence over numbers, figures, references, or guidance presented in other chapters of this manual.

2-2. Photogrammetric Mapping Standards

There are five generally recognized industry standards that can be used for specifying spatial mapping products and resultant accuracy compliance criteria:

a. Office of Management and Budget (OMB) "United States National Map Accuracy Standards" (Bureau of the Budget 1947).

b. Photogrammetry for Highways Committee "Reference Guide Outline: Specifications for Aerial Surveys and Mapping by Photogrammetric Methods for Highways" (Photogrammetry for Highways Committee 1968).

c. US Department of Transportation (DOT) "Surveying and Mapping Manual" (Miller 1985).

d. American Society for Photogrammetry and Remote Sensing (ASPRS) "ASPRS Accuracy Standards for Large-Scale Maps (ASPRS 1990).

e. US National Cartographic Standards for Spatial Accuracy.

Each of these standards has application to different types of functional products, ranging from wide-area small-scale mapping (OMB National Map Accuracy Standards) to large-scale engineering design (ASPRS Accuracy Standards for Large-Scale Maps). Their resultant accuracy criteria (i.e., spatial errors in X-Y-Z), including QC compliance procedures, do not differ significantly from one another. In general, use of any of these standards for a photogrammetric mapping contract will result in a quality product.

2-3. USACE Photogrammetric Mapping Standard

The recommended standard for USACE photogrammetric mapping is the ASPRS Accuracy Standards for Large-Scale Maps (ASPRS 1990). This standard was developed and is generally recognized by the photogrammetric industry, and is specifically concerned with definitions of spatial accuracies for engineering projects typical of those designed by USACE. This standard is intended for site plan development work involving mapping scales larger than 1:20,000, usually in the range of 1 in. = 20 ft to 1 in. = 100 ft. Its primary advantage over other standards is that it contains more definitive statistical map testing criteria, which, from a contract administration standpoint, is desirable. It also is applicable to conventional surveying topographic site development work. For small-scale general location mapping work (i.e., scales smaller than 1:20,000), any of the other mapping standards in paragraph 2-2 may be specified. The OMB National Map Accuracy Standards (Bureau of the Budget 1947) is perhaps the most widely used standard and is recommended for smaller scale mapping work.

a. Application of standards. The objective of these photogrammetric standards is twofold:

(1) To help assure that the topographic map accuracy standards will be met during the production process.

(2) To help assure that contractual deliverables other than maps, such as aerial photographs, ground control, etc., will possess quality of the required degree.

USACE photogrammetric mapping criteria relating to the recommended ASPRS standards are presented in this chapter and throughout the manual. Other USACE-specific criteria required in addition to the ASPRS standards are also given.

b. Map accuracy subclassifications. Three map accuracy classifications are prescribed in the ASPRS standards. These classes are discussed in paragraph 2-4a. Lower classifications will be more economical. The project engineer/manager must determine the specific map accuracy requirement and class for a given project based on the functional requirements. This determination cannot be done by the USACE Command survey function or the photogrammetric mapping contractor. (Further guidance on selecting mapping target scales as a function of an engineering project is contained in later chapters of this manual.) The accuracy class must be shown on all final drawings/design files.

c. Use of ASPRS standards for conventional mapping. The ASPRS standards are also applicable to large-scale site plan mapping performed by plane table or electronic total station techniques. This work may either supplement the aerial mapping work (e.g., surface or subsurface utility details) or be of a scale too large for aerial mapping (generally larger than 1 in. = 40 ft).

d. Compliance tests. Tests for compliance with the ASPRS and other map accuracy standards are discussed in more detail in Chapter 3, Quality Control and Quality Assurance Standards. Maps found compliant with a particular standard shall have a statement indicating that standard. The compliance statement shall refer to the data of lowest accuracy depicted on the map. Published maps whose errors exceed those given in a standard shall omit from their legends all mention of standard accuracy.

2-4. ASPRS Accuracy Standards for Large-Scale Maps

In March 1990, the Professional Practicing Division, ASPRS, approved a set of standards as guidelines for large-scale mapping (Appendix D). These standards have been designed for large-scale planimetric and topographic maps prepared for engineering applications and other special purposes. Emphasis is placed on the final spatial accuracies that can be derived from the map in terms most generally understood by users. These ASPRS standards, and recommended USACE standards, are synopsized below.

a. Map classes. Three map accuracy classes are defined. Class 1 maps are the most accurate. Class 2 maps have twice the root mean square error (RMSE) of a Class 1 map; Class 3 maps have thrice the RMSE of a Class 1 map. Maps may be one class in horizontal accuracy and another in vertical.

b. Horizontal accuracy criteria. The planimetric standard makes use of the RMSE as being "...defined to be the square root of the average of the squared discrepancies." It goes on to state: "...the discrepancies are the differences in coordinate or elevation values as derived from the map and as determined by an independent survey of higher accuracy (check survey)." The RMSE is defined in terms of feet or meters at ground scale rather than in inches or millimeters at the target map scale. This results in a linear relationship between RMSE and target map scale; as map scale decreases, the RMSE increases linearly. The RMSE is the cumulative result of all errors including those introduced by the processes of ground control surveys, map compilation, and final extraction of ground dimensions from the target map. The limiting RMSE's shown in Table 2-1 are the maximum permissible RMSE's established by this standard. These limits of accuracy apply to well-defined points only.

Table 2-1
Planimetric Feature Coordinate Accuracy Requirement (Ground X or Y in Feet) for Well-Defined Points

Target Map Scale		Limiting RMSE in X or Y		
1 in. = x ft	Ratio, ft/ft	Class 1	Class 2	Class 3
5	1:60	0.05	0.10	0.15
10	1:120	0.10	0.20	0.30
20	1:240	0.2	0.4	0.6
30	1:360	0.3	0.6	0.9
40	1:480	0.4	0.8	1.2
50	1:600	0.5	1.0	1.5
60	1:720	0.6	1.2	1.8
100	1:1,200	1.0	2.0	3.0
200	1:2,400	2.0	4.0	6.0
400	1:4,800	4.0	8.0	12.0
500	1:6,000	5.0	10.0	15.0
800	1:9,600	8.0	16.0	24.0
1,000	1:12,000	10.0	20.0	30.0
1,667	1:20,000	16.7	33.3	50.0

c. Vertical accuracy criteria. Vertical accuracy is defined relative to the required contour interval (CI) for a map. In cases where only digital elevation models are being generated, an equivalent CI must be specified, based on the required digital point (spot) elevation accuracy. (The contours themselves may be later generated using CADD software routines.) The vertical standard also uses the RMSE, but only for well-defined features between contours containing interpretative elevations, or spot elevation points. (Contours in themselves are not considered as well-defined feature points.) The RMSE for Class 1 contours is one-third of the CI. The RMSE for Class 1 spot heights is one-sixth of the CI. Class 2 and Class 3 accuracies are twice and thrice those of Class 1, respectively. Testing for vertical map compliance is also performed by independent, higher accuracy ground survey methods, such as differential leveling. Table 2-2 summarizes the limiting vertical RMSE's for well-defined points, as checked by independent surveys at the full (ground) scale of the map.

d. Map accuracy testing. Horizontal' and vertical accuracy is to be checked by comparing measured coordinates or elevations from the map (at its intended target scale) with coordinates determined by a check survey of higher accuracy. Comparison survey accuracies are defined by relative distance accuracy ratios, as determined from the error propagation resulting within a minimally constrained, properly weighted, least squares adjustment. (This is not the same statistic as a simple traverse or level line misclosure.)

(1) For horizontal points, the check survey should produce a standard deviation equal to or less than one-third of the limiting RMSE selected for the map. This means that the relative distance accuracy ratio of the check survey must be less than one-third that of the limiting RMSE, expressed as a function of the distance measured across the map sheet (not overall project or design file) diagonal.

(2) For example, given a 1-in. = 50-ft target scale with a required horizontal feature accuracy of 0.5 ft (i.e., Table 2-1, Class 1 accuracy) and a typical diagonal distance of 40 in. across a standard sheet, the check survey should have a relative accuracy of 1:12,000, or Second-Order, Class II (50 ft/in. by 40 in./0.5 ft/3). This accuracy level is constant for all scales plotted on a standard drawing sheet with approximately a 40-in. dimension.

Table 2-2
Topographic Elevation Accuracy Requirement for Well-Defined Points

Target CI, ft	Limiting RMSE, ft					
	Topographic Feature Points for Class			Spot or Digital Terrain Model Elevation Points for Class		
	1	2	3	1	2	3
0.5[a]	0.17	0.33	0.50	0.08	0.16	0.25
1	0.33	0.66	1.0	0.17	0.33	0.5
2	0.67	1.33	2.0	0.33	0.67	1.0
4	1.33	2.67	4.0	0.67	1.33	2.0
5	1.67	3.33	5.0	0.83	1.67	2.5

[a] Obtaining differential elevation accuracies at or below the 0.5-ft contour level requires specialized aircraft/platforms and/or cameras—use conventional ground topo survey methods below the 0.2-ft level.

(3) Only the dimensions of a typical sheet, not the overall project or design file dimensions, are used to compute relative line accuracies. This is true regardless of whether the data are contained in an overall digital design file—the critical parameter for engineering and construction is relative accuracy of map features within the range of a drawing/sheet.

(4) Thus for a typical 40-in. plot on a standard F-size drawing sheet, the relative line accuracy check surveys in Table 2-3 must be run to check the map product. For smaller drawing/site sizes, the relative accuracies would be adjusted downward accordingly.

Table 2-3
Horizontal Control Survey Standards for 40-in. Drawing

Map Class	Relative Accuracy	Survey Standard
1	1:12,000	2nd, Class II
2	1: 6,000	3rd, Class I
3	1: 4,000	3rd, Class II

(5) For vertical points, the check survey (i.e., differential leveling or electronic total station trig elevations) should produce an RMSE not greater than 1/20th of the CI, expressed relative to the longest diagonal dimension of a standard drawing sheet (approximately 40 in.). The map position of the ground point may be shifted in any direction by an amount equal to twice the limiting RMSE in horizontal position. Conventional Third-Order leveling procedures and standards will be of sufficient accuracy to provide reliable check surveys for all photogrammetric map classes with a CI of 1 ft or larger. Again, as with horizontal evaluation, vertical check survey accuracies are relative to the area on a given map sheet, not to the overall project dimension.

(6) The same survey datums must be used for both the mapping and check surveys.

(7) Refer to Chapter 3 for additional details on map testing criteria.

e. Checkpoints. As mentioned earlier, checkpoints should be confined to well-defined points, such as road intersections, etc. Depending upon map scale, certain features will be displaced for the sake of map clarity. These points should not be used unless the rules for displacement are well known and can be counteracted. A minimum of 20 checkpoints per map sheet are required. These should be well distributed over the map sheet. Any checkpoint whose discrepancy exceeds three times the limiting RMSE should be corrected before the map is considered to meet the standard.

f. Map testing requirements. Tests for compliance of a map sheet are optional. One or more sheets (or segments of a design file) may be tested for compliance. The decision on whether to check work on a particular project rests with the Contracting Officer or his designated representative, and is dependent on numerous factors, such as intended design work, available personnel, known contractor capabilities, and personnel resources available for the test. Map testing can be a significant percentage of the overall project cost in some cases. Procedures for rejecting unsatisfactory work based on unacceptable map tests are contained in USACE guide specifications for surveying service contracts.

g. Compliance statement. Maps (or the appropriate digital design file descriptor level) produced to meet the ASPRS standard shall include the following statement:

THIS MAP WAS COMPILED TO MEET THE ASPRS STANDARD FOR CLASS *[__] MAP ACCURACY

If the map was field checked and found compliant, the following additional statement shall be added:

THIS MAP WAS CHECKED AND FOUND TO CONFORM TO THE ASPRS STANDARD FOR CLASS *[__] MAP ACCURACY

For digital products, the descriptor level should also contain the original target mapping scale along with the absolute horizontal and vertical accuracies intended or checked.

2-5. United States National Map Accuracy Standards

In 1941, a US Bureau of the Budget (now OMB) circular established guidelines for maps produced by Federal civilian agencies, the United States National Map Accuracy Standards (USNMAS). These standards were developed primarily for smaller scale topographic mapping, such as the US Geological Survey (USGS) 1:24,000 quadrangle mapping program. In many cases, the USNMAS have also been adapted by several non-Federal and Department of Defense agencies to their specific requirements. These standards may be used for USACE mapping at scales smaller than 1:20,000. For scales larger than 1:20,000, use of the ASPRS standards is recommended.

a. US National Map Accuracy Standards. Reproduced below are the standards:

EXECUTIVE OFFICE OF THE PRESIDENT
Bureau of the Budget
Washington, D.C. 20503

June 10, 1941 — Revised April 26, 1943
Revised June 17, 1947

UNITED STATES NATIONAL MAP ACCURACY STANDARDS

With a view to the utmost economy and expedition in producing maps which fulfill not only the broad needs for standard or principal maps, but also the reasonable particular needs of individual agencies, standards of accuracy for published maps are defined as follows:

I. Horizontal Accuracy. For maps on publication scales larger than 1:20,000, not more than 10 percent of the points tested shall be in error by more than 1/30 inch, measured on the publication scale; for maps on publication scales of 1:20,000 or smaller, 1/50 inch. These limits of accuracy shall apply in all cases to positions of well defined points only. "Well defined" points are those that are easily visible or recoverable on the ground, such as the following: monuments or markers, such as bench marks or property boundary monuments; intersections of roads, railroads, etc.; corners of large buildings or structures (or center points of small buildings), etc. In general what is "well defined" will also be determined by what is plottable on the scale of the map within 1/100 inch. Thus while the intersection of two road or property lines meeting at right angles would come within a sensible interpretation, identification of the intersection of such lines meeting at an acute angle would obviously not be practicable within 1/100 inch. Similarly, features not identifiable upon the ground within close limits are not to be considered as test points within the limits quoted, even though their positions may be scaled closely upon the map. In this class would come timberlines, soil boundaries, etc.

II. Vertical accuracy, as applied to contour maps on all publication scales, shall be such that not more than 10 percent of the elevations tested shall be in error more than one-half the contour interval. In checking elevations taken from the map, the apparent vertical error may be decreased by assuming a horizontal displacement within the permissible horizontal error for a map of that scale.

III. The accuracy of any map may be tested by comparing the positions of points whose locations or elevations are shown upon it with corresponding positions as determined by surveys of a higher accuracy. Tests shall be made by the producing agency, which shall also determine which of its maps are to be tested and the extent of such testing.

IV. Published maps meeting these accuracy requirements shall note this fact on their legends, as follows: "This map complies with national map accuracy standards."

V. Published maps whose errors exceed those aforestated shall omit from their legends all mention of standard accuracy.

VI. When a published map is a considerable enlargement of a map drawing (manuscript) or of a published map, that fact shall be stated in the legend. For example, "This map is an enlargement of a 1:20,000-scale map drawing," or "This map is an enlargement of a 1:24,000-scale published map."

VII. To facilitate ready interchange and use of basic information for map construction among all Federal map making agencies, manuscript maps and published maps, wherever economically feasible and consistent with the uses to which the map is to be put, shall conform to latitude and longitude boundaries, being 15 minutes of latitude and longitude, or 7-1/2 minutes, or 3-3/4 minutes in size.

b. Compliance statement. Maps in compliance with the USNMAS shall include the following statement:

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS

2-6. American Society of Photogrammetry Specifications for Aerial Surveys and Mapping by Photogrammetric Methods for Highways

These standards, developed in 1968 (Photogrammetry for Highways Committee 1968), are quite similar to the DOT standards contained in paragraph 2-7. Use of these standards is optional for USACE Commands.

a. Contours. Ninety percent of the elevations determined from the solid-line contours of the topographic maps shall have an accuracy with respect to true elevation of one-half CI or better and the remaining 10 percent of such elevations shall not be in error by more than one CI.

b. Coordinate grid lines. The plotted position of each plane coordinate grid line shall not vary by more than 1/100 in. from true grid value on each map manuscript.

c. Horizontal control. Each horizontal control point shall be plotted on the map manuscript within the coordinate grid in which it should lie to an accuracy of 1/100 in. of its true position as expressed by the plane coordinates computed for the point.

d. Planimetric features. Ninety percent of all planimetric features that are well-defined on the photographs shall be plotted so that their position on the finished maps shall be accurate to within at least 1/40 in. of their true coordinate position, as determined by the test surveys, and none of the features tested shall be misplaced on the finished maps by more than 1/20 in. from their true coordinate position.

e. Special requirements. When stipulated in the contract or delivery order scope of work, all specified features shall be delineated on the maps, regardless of whether they can be seen on the aerial photographs and on stereoscopic models formed therefrom. The contractor shall complete compilation by conventional field surveys on the ground to comply with all accuracy and completeness stipulations.

f. Spot elevations. Ninety percent of all spot elevations placed on the maps shall have an accuracy of at least one-fourth the CI, and the remaining 10 percent shall not be in error by more than one-half the CI.

2-7. DOT Map Standards

In 1985, DOT published its "Surveying and Mapping Manual" (Miller 1985). Section 3-80-01 of this manual defines five types of maps: planimetric maps, whose only indication of relief is by spot heights; topographic maps, which show contours and additional spot heights as needed; cadastral maps; which show property ownership; planimetric-cadastral maps; and topographic-cadastral maps. The standards for these maps are abstracted in a-d below. Use of these standards is optional for USACE Commands.

a. Cadastral data. Coordinates of property boundary points must be plotted so that their distance from the nearest grid lines are not in error by more than 1/100 in. The map shall show all property boundary lines connecting property boundary points. Coordinates of property boundary points may have been determined by field traverse or by analytical aerial triangulation. Owners' names or designations, coordinates, and property boundary point symbols shall be shown on the map.

b. Contours. At least 90 percent of all tested contours shall be in error by no more than one-half of the CI. This applies only to the contours that appear on the map, regardless of the stated CI. Contours cannot be shifted horizontally in an attempt to meet the criterion. All representable topographic features visible on the aerial photographs must be depicted on the map.

c. Spot heights. For topographic maps, the labeled elevation of at least 90 percent of the spot elevations tested shall not differ from the true elevation by more than one-fourth of the CI, and none by more than one-half of the CI, or for maps produced photogrammetrically, the RMSE of the elevations of all of the spot elevations tested shall not exceed 1/5,000th of the flight height of the photography (H/5,000), whichever is less restrictive. For planimetric maps, the RMSE of the elevation in feet of all the spot elevations tested shall not exceed 1/60th of the map scale expressed in feet to 1 in., or for maps produced photogrammetrically, 1/4,000th of the flight height of the photography (H/4,000), whichever is less restrictive.

d. Coordinate grid lines. On the finished map, no measurement of 3 ft or less between coordinate grid lines shall differ from the correct distance by more than 1/100 in. No two measured distances of 3 ft or less, with diagonals of a rectangle bounded by coordinate grid lines, shall differ from each other by more than 1/100 in. No horizontal control point tested may be located on the finished map so that its position in relation to the adjacent coordinate grid lines differs from its true coordinate position by more than 1/100 in. The location of a control point is the center of the plotted symbol representing the control point or the center of the image of the target placed over the control point.

2-8. United States National Cartographic Standards for Spatial Accuracy

The USNMAS is in the process of being revised. A draft for review has been prepared by USGS. These standards appear more applicable to small-scale mapping work such as that performed by the USGS. Like the ASPRS (1990) standards, this standard allows for three accuracy classifications based on RMS positional errors. The ASPRS standards may be used in lieu of the USNMAS for small-scale mapping if desired. The draft is reproduced verbatim as follows:

UNITED STATES NATIONAL CARTOGRAPHIC STANDARDS FOR SPATIAL ACCURACY

These standards concern the definitions of spatial accuracy as they pertain to cartographic data, both digital and graphic, prepared or utilized by federal agencies.

I. Horizontal Accuracy. For cartographic data intended for publication at 1:250,000 scale and larger, the root mean square (rms) error in either the x or y coordinates will not exceed 0.25 mm, measured on the intended publication scale. These limits of accuracy shall apply in all cases to positions of well-defined points.

II. Vertical Accuracy. For elevation data, the rms error will not exceed one-third of the published or planned contour interval. For purposes of checking elevations, the apparent vertical error at each test point may be reduced by shifting the position in any direction by 0.50 mm. Spot elevations shall be given within a limiting rms error of one-sixth of the published contour interval.

III. Accuracy Test. The accuracy of any cartographic product may be tested by comparing the positions or elevations of points with corresponding positions or elevations as determined by surveys of a higher accuracy. The rms error will be calculated separately for each coordinate tested using all of the test point discrepancies. Tests for compliance of a product are optional. Products may be tested for either horizontal or vertical accuracy or both.

IV. Cartographic Products. Those products meeting both horizontal and vertical accuracy requirements shall carry the note:

COMPLIES WITH NATIONAL CARTOGRAPHIC STANDARDS FOR SPATIAL ACCURACY

Products failing either horizontal or vertical accuracy requirements, or both, will display "Complies with National Cartographic Standards for Spatial Accuracy - Class ___". The rms errors for Class 2 products will not exceed 0.50 mm in the x or y coordinates and two-thirds of the contour interval in the vertical. All products that exceed those limits will be Class 3.

V. Product Series. Sample testing is permitted for determining the class level of a series of one hundred or more cartographic products that were made using similar instruments, procedures, and materials. At least three percent (but not less than 30) of the series will be tested and the call of the whole series will be based on the results. If 90 percent or more of the products tested meet the class intended, then the whole production group will be certified as meeting that class.

VI. Nonstandard Products. Those products produced in areas where it is impractical to meet or test for compliance with these standards (e.g. due to dense timber or foliage) will not carry an accuracy statement.

2-9. Typical Mapping Scales, Contour Intervals, and Accuracy Classifications for USACE Functional Applications

Table 2-4 depicts typical mapping parameters for various USACE engineering, construction, and real estate mapping applications. The table is intended to be a general guide in selecting a target scale for a specific project; numerous other project-specific factors may dictate variations from these general values. The table does not apply exclusively to photogrammetric mapping activities—some of the required surveying and mapping accuracies identified exceed those obtainable from photogrammetry and may need to be obtained using conventional surveying techniques. Selection of an appropriate CI is extremely site-dependent, and will directly impact the mapping costs since the photo negative scale (and resultant model coverage and ground survey control) is determined as a function of this parameter. Table 2-5 may be used as general guidance in selecting a CI (or Digital Terrain Mapping (DTM) elevation accuracy, as applicable). See also additional guidance in subsequent chapters dealing with photo mapping planning and cost estimating.

2-10. Supplemental USACE Photogrammetric Mapping Criteria

The following criteria shall be followed (and/or referenced) in preparing contract specifications or delivery order scopes of work for photogrammetric mapping services.

a. Non-SI/SI conversion. Conversions between non-SI units and SI units of measure shall be as follows:

(1) 1 in. = 25.4 mm exactly

(2) 1 International Foot = 0.3048 m exactly

(3) 1 US Survey Foot = 1,200/3,937 m exactly

b. Maximum enlargement for map compilation from negative to map scale. The maximum enlargement from original negative scale to final map scale shall conform to Table 2-6.

c. Maximum allowable C-factor ratios. The C-factor ratios in Table 2-7 shall not be exceeded for any class of photogrammetric mapping used for engineering and design.

d. Minimum negative scales for planimetry. Table 2-8 depicts the minimum allowable negative scale (and related flight altitude for a 6-in. focal length camera) for a given target mapping scale. These minimum scales are based on prescribed enlargement limitations given in Table 2-6, and are intended for large-scale engineering and design site plan mapping work. The negative scale shown in the table is simply computed by multiplying the target scale times the maximum allowable enlargement ratio prescribed in Table 2-6.

e. Minimum negative scale for topographic development. The minimum negative scales in Table 2-9 shall be used relative to the vertical contour accuracy intended for the product. These limiting negative scales, along with limitations based on the planimetric component, will be used in determining the optimum negative scale for a project. The limiting negative scales are computed based on the prescribed C-factor ratio limits given in Table 2-7 (multiplied by the CI and divided by 6). In some instances, a different scale will be flown for the horizontal planimetry and for the vertical topography. This most often occurs when a 1-ft CI is required at a relatively small mapping scale, say 1 in. = 100 to 200 ft.

f. Photo control survey standards and specifications. In general, Third-Order control surveys will be adequate for controlling most large-scale photogrammetric mapping projects. USACE survey standards and specifications for engineering and construction surveying are in the process of being developed. These standards will be based on relative loop closure criteria rather than Federal Geodetic Control Committee (FGCC) relative line accuracy criteria. The FGCC standards

Table 2-5
Selection of CI

CI, ft	General Purpose
1	Final design, excavation and grading plans, earthwork computations for bid estimates, and contract measurement and payment.
2	Route location, preliminary alignment and design.
4-5	Preliminary project planning, hydraulic sections, rough earthwork estimating.
10-20	High-gradient terrain, low unit cost earthwork excavation estimates, scaled/digitized directly from existing USGS quad maps.

Table 2-6
Maximum Enlargement Ratios from Photographic Scale to Map Scale

Instrument Type	Measurement Accuracy at Photo Scale mm	Maximum Enlargement Photo to Map		
		Map Class	Planimetric Map	Topographic Map
Analytical Stereoplotter	0.003 - 0.005	1	7	
		2	8	—[1]
		3	9	
Analog Stereoplotter (Mechanical First-Order)	0.010 - 0.015	1	6	
		2	7	—[1]
		3	8	
Air Photo Plan Sheets (Optimum)	N/A	N/A	4	—
	N/A	N/A	1.5	—
Ortho Photos	—	1	4	—
	—	2	6	—
	—	3	8	—
Second-Order Mechanical Stereoplotter[2]	0.015 - 0.025	1	5	4
		2	6	5
		3	7	6
Third-Order Direct-Optical Stereoplotter[2]	0.030 - 0.050	1	N/A	N/A
		2	5	N/A
		3	5	5

[1] Topographic enlargement limitations are a function of the CI and C-factor (Table 2-9).
[2] These older, near-obsolete types of plotters should not be specified in a USACE photogrammetric mapping service contract.

Table 2-7
Maximum C-Factor Ratios (Denominator)

Stereoplotter	Class 1	Class 2	Class 3
Analytical	2000	2200	2500
First-Order Analog/Mechanical	1600	1800	2000

Table 2-8
Minimum Negative Scales and Maximum Flight Altitudes for Planimetric Mapping

Target Scale 1 in. = x ft	First-Order Analog/Mechanical			Analytical		
	Class 1	Class 2	Class 3	Class 1	Class 2	Class 3
5	—	—	—	—	—	—
10	—	—	—	—	—	—
20	—	—	—	140 [840]	160 [960]	180 [1,080]
30[a]	—	—	—	210 [1,260]	240 [1,440]	270 [1,620]
40	240 [1,440]	280 [1,680]	320 [1,920]	280 [1,680]	320 [1,920]	360 [2,160]
50	300 [1,800]	350 [2,100]	400 [2,400]	350 [2,100]	400 [2,400]	450 [2,700]
60	360 [2,160]	420 [2,520]	480 [2,880]	420 [2,520]	480 [2,880]	540 [3,240]
100	600 [3,600]	700 [4,200]	800 [4,800]	700 [4,200]	800 [4,800]	900 [5,400]
200	1,200 [7,200]	1,400 [8,400]	1,600 [9,600]	1,400 [8,400]	1,600 [9,600]	1,800 [10,800]
400	2,400 [14,400]	2,800 [16,800]	3,200 [19,200]	2,800 [16,800]	3,200 [19,200]	3,600 [21,600]
>400[b]						

Notes:
1. Minimum negative scale in feet per inch shown above maximum flight altitude in feet shown in brackets.

[a] Mapping scales larger than 1 in. = 30 ft require nonstandard aircraft, special cameras and mounts, close-range photogrammetry, and/or ground survey methods. These large scales are difficult to obtain from fixed-wing aircraft due to low-altitude restrictions and image motion.

[b] Scales above 1 in. = 400 ft are not generally applicable to detailed design work, but are for general location or feasibility planning mapping. Specially equipped aircraft will be required at the higher altitudes. Twelve-inch (or longer) focal length cameras may also be used for these small-scale maps.

(FGCC 1984) may be used pending development of USACE survey standards.

g. Aerotriangulation accuracy standards. Aerotriangulation accuracy for each class of map and orthophotograph shall conform to Table 2-10.

2-11. USACE Orthophoto and Orthophoto Map Accuracy Standards

This section sets forth the standards for orthophotos and orthophoto maps. Each orthophoto shall meet the quality and precision specified in the contract. USACE standards for orthophoto mapping will conform to the USNMAS. A USACE Class 1 orthophoto map is equivalent to the USNMAS. Two lower-order USACE orthophoto map classes are added to the USNMAS. Use the guidance shown in Table 2-11 to determine if simple or differential rectification is required. Differentially rectified (controlled) orthophotos or orthophoto maps should not be specified when less costly semicontrolled or uncontrolled air photo enlargement plans would suffice. Additional orthophoto mapping criteria are found in Chapter 9.

Table 2-9
Minimum Negative Scale and Maximum Flight Altitudes for Topographic Development

	First-Order Analog/Mechanical			Analytical		
CI, ft	Class 1	Class 2	Class 3	Class 1	Class 2	Class 3
1/2	133 [800]	150 [900]	167 [1,000]	167 [1,000]	183 [1,100]	208 [1,250]
1	267 [1,600]	300 [1,800]	333 [2,000]	333 [2,000]	367 [2,200]	417 [2,500]
2	533 [3,200]	600 [3,600]	667 [4,000]	667 [4,000]	733 [4,400]	833 [5,000]
4	1,067 [6,400]	1,200 [7,200]	1,333 [8,000]	1,333 [8,000]	1,467 [8,800]	1,667 [10,000]
5	1,333 [8,000]	1,500 [9,000]	1,667 [10,000]	1,667 [10,000]	1,833 [11,000]	2,083 [12,500]
10	2,667 [16,000]	3,000 [18,000]	3,333 [20,000]	3,333 [20,000]	3,667 [22,000]	4,167 [25,000]

Note:
1. For each CI, the minimum negative scale in feet per inches is shown above the maximum flight altitude in feet in brackets; based on a standard 6-in. focal length camera.

Table 2-10
Aerotriangulation Accuracy Criteria

		Allowable Error at Control and Test Points			
		Horizontal		Vertical	
Map Class	Aerotriangulation Method	RMSE	Maximum	RMSE	Maximum
1	Fully Analytical	H/10,000	3 RMSE	H/9,000	3 RMSE
2	Fully Analytical	H/8,000	3 RMSE	H/6,000	3 RMSE
3	Fully Analytical or Semianalytical	H/6,000	3 RMSE	H/4,500	3 RMSE

a. Photographic detail. The ground surface, vegetation, culture, and all other details shall be clearly discernable.

b. Accuracy. Orthophotos shall depict all visible image features in the correct planimetric position to the accuracy specified in subparagraph *c* below. Image displacements caused by ground relief and by tilt shall be removed. Topographic line and point data shall meet the topographic map standards previously set forth in this chapter.

c. Orthophoto accuracy classes. For Class 1 orthophotos, 90 percent of all photographic details on the orthophotograph shall be accurate to within at least 1/40 in. of true position, as determined by test surveys, and none of the photographic details shall be displaced by more than 1/20 in. from true coordinate position. Class 2 and Class 3 accuracy standards shall be two and three times Class 1 standards, respectively. Table 2-12 summarizes these standards. Class 1 orthophotos will generally be required only when detailed design is superimposed on the print, usually at scales greater than 100 ft/in. Since the orthophoto process rectifies images at the ground elevation of a DTM scan, accuracy standards must exclude objects above and below the scan elevation, such as tops of buildings, poles, trees, and other like objects.

Table 2-11
Requirements for Differential Rectification Based on Project Relief

Scale ft/in.	Differential Rectification Required if Relief Exceeds Amount Shown (in feet)—Otherwise Use Simple Rectification		
	Class 1	Class 2	Class 3
50	1.5	3	4.5
100	3	6	9
200	6	12	18
400[a]	12	24	36
1,000[a]	30	60	90

[a] At scales smaller than 400 ft/in., which are used only for general site reference, simple air photo enlargements should be used in lieu of costly orthophoto differential rectification. Simple air photo plans may be controlled (rectified to photo identifiable ground control), semicontrolled (rectified to USGS 1:24,000 maps), or uncontrolled (no rectification).

Table 2-12
Summary of Orthophoto and Orthophoto Map Accuracy at Publication Scale

Class	Accuracy	
	Percent	In.
1	90	1/4
	100	1/20
2	90	1/20
	100	1/10
3	90	1/13
	100	1/6

d. Compliance statement. Orthophoto maps in compliance with the USNMAS shall include the following statement:

THIS ORTHOPHOTO MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS

(1) Maps found compliant with a USACE Class 2 or Class 3 orthophoto map accuracy standard will include the following statement:

THIS ORTHOPHOTO COMPLIES WITH USACE STANDARD FOR CLASS *[__] ACCURACY

(2) The compliance statement shall refer to the data of lowest accuracy depicted on the orthophoto.

(3) Published maps whose errors exceed those aforestated shall omit from their legends all mention of standard accuracy.

e. Scan lines. The final orthophoto (map) shall not contain scan lines and mismatched imagery that interfere with the interpretability of ground features or that are aesthetically objectionable. Mismatches exceeding 1/20 in. are generally unacceptable and may be cause for rejection.

f. Photographic tone. The photographic negative of the orthophotograph shall have uniform color tone, and shall have the appropriate degree of contrast that will cause all details to show clearly in the dark-tone areas and in the highlight areas as well as in the halftones between the dark and highlight. Negatives having excessive contrast or low contrast may be rejected. Exposure scan lines shall not be noticeable or detracting from the photographic details.

g. Artifacts. The orthophoto (map) shall not contain out-of-focus imagery, dust marks, scratches, and inconsistencies in tone and density between individual orthophotos and/or adjacent map sheets.

h. Enlargement ratio. The enlargement from the aerial negative to orthophoto publication scale shall not exceed four times for Class 1, six times for Class 2, and eight times for Class 3.

i. Obscured cultural and other topographic data. Data obscured on the aerial photographs shall be added to the orthophoto map in conventional graphical form. If a building or other nonlinear feature is partly obscured, its entire outline or other representation shall be graphical. These data shall be from field surveys on the ground, previously compiled line data (separates, etc.), or photogrammetric stereocompilation.

j. Photographic film. Only fine-grain photographic film on a dimensionally stable base shall be used for exposing the initial negative of each orthophotograph as it is compiled. Outdated film shall not be used.

k. Sample orthophotos. Image quality and exposure shall not be less than that provided to USACE by the Contractor as sample orthophotography if this is a required submittal item during contract negotiations.

l. Digital resampling. Orthophotographs that have been created by digital processing shall have been resampled by bilinear, cubic convolution, or equivalent algorithm. Nearest neighbor resampling shall not be acceptable.

m. Screening. Final reproducible sheets shall be halftone-screened positives on a polyester base with a minimum thickness of 0.004 in. Screening shall be 120 lines per inch, unless otherwise specified by contract. For composite orthophoto and contour reproducibles, only the photographic image shall be halftone screened.

2-12. USACE Digital Data Product Accuracy Standards

a. General. A DTM shall consist of three-dimensional coordinates of points taken in a specified pattern and recorded on a computer-compatible media.

b. Coordinate systems. A DTM shall consist of three coordinates for each point measured, recorded on the specified media. Coordinates shall be in the system authorized for the project. Elevations and horizontal coordinates shall be recorded to the nearest 1/10 ft or better at ground scale. For small-scale mapping, elevations may be recorded to the nearest foot.

c. Grid. The horizontal coordinate system for a grid DTM shall have its axes parallel to the axes of the grid.

d. Cross sections. Horizontal coordinates for cross sections shall be center-line or baseline stationing, and offset from center line or baseline. All offsets left of center line shall be negative and all offsets right of center line must be positive, unless otherwise approved by the USACE Contracting Officer.

e. Remeasurement. The coordinate system for remeasurement shall be the same as was used for the original measuring. Elevations shall be taken at the same points on the grid or along the same cross sections that were measured for original data. In addition, measurements shall be taken along the grid lines or cross-section lines at the change from original ground to earthwork and at significant breaks in the earthwork surface.

f. Critical points. Coordinates shall be measured and recorded for enough points to define the topography completely and accurately. Break (hinge) lines (along crests, valleys, etc.) shall be defined by points at all breaks, and all points making up the same break line shall be so identified. In addition, other points shall be measured and recorded to define the shape of the terrain between break lines. The maximum spacing of points shall be as specified by USACE.

g. Obscured areas. When the DTM model is produced photogrammetrically, and there are areas where structures, brush, or tree cover obscure the ground so that the DTM cannot be measured completely and accurately from the photographs, the data necessary to complete the work shall be secured by ground surveys.

h. Accuracy. The RMSE in feet of the elevations of all points tested shall not exceed the limit specified in the contract or delivery order. No individual error shall exceed three times the specified limit for RMSE. The average error (the algebraic sum of the individual test point errors, taking into consideration their signs, divided by the number of test points) shall not exceed 0.3 times the specified limit for the RMSE. The RMSE and the average error for any individual cross section or any individual group of grid points shall not exceed twice the limits established for the entire DTM.

i. Recordation of data. Stereoplotters used to measure coordinates photogrammetrically shall be equipped with encoders that sense the instrument settings and transmit them in digital form. The coordinates shall be recorded by the stereoplotter directly onto the media.

2-13. Photogrammetric Mapping Coverage

Table 2-13 depicts various aerial photo mapping parameters that may be used for mission planning purposes.

Table 2-13
Standard Photogrammetric Mapping Coverage Parameters

Photo Negative Scale, ft/in.	9- by 9-in. Full Photo Width ft sq	9- by 9-in. Full Photo Coverage acres	Flight Line Spacing, ft	Lineal Gain Per Exposure, ft	Net Model Gain acres
166	1,500	52	1,050	600	15
200	1,800	74	1,260	720	20
250	2,250	116	1,575	900	32
300	2,700	167	1,890	1,080	46
400	3,600	297	2,520	1,440	83
500	4,500	465	3,150	1,800	130
600	5,400	669	3,780	2,160	187
1,000	9,000	1,860	6,300	3,600	520
1,200	10,800	2,678	7,560	4,320	750
1,667	15,000	5,165	10,500	6,000	1,446
2,000	18,000	7,438	12,600	7,200	2,082

Notes:
1. Coverage parameters based on standard 6-in. camera, 9- by 9-in. negative size, 60 percent end lap, and 30 percent side lap. Net Model Gain = 28 percent (i.e., 0.4 by 0.7) of full photo coverage.
2. 1 acre = 43,560 square feet (sq ft)
3. 1 square mile (or section) = 640 acres