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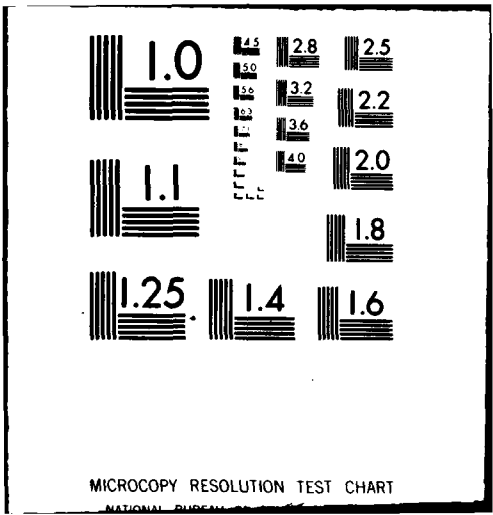
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Status of the Vertical Geodetic Data at the  
Defense Mapping Agency Hydrographic / Topographic Center  
for Mexico and Central America

by

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## ABSTRACT

Since 1946, the Defense Mapping Agency (DMA) has been participating with Mexico and each of the Central American countries, as a result of the collaborative program under the Inter American Geodetic Survey for the production of cartographic, geodetic, and geophysical products. The geodetic leveling network, which developed from these mapping agreements with each country, now contains over 50,000 kilometers of leveling. Gravity observations have also been observed over a large portion of these level lines. Most of these leveling data were adjusted by DMA in regional blocks as the basic leveling networks were completed. Each regional block was adjusted, holding mean-sea-level at the tidal stations equal to zero. Elevations of previously adjusted blocks were held fixed in each successive block adjustment. A test adjustment (1980) combining all of the first-order level links from the 1959 to 1972 regional adjustments was performed for analysis. Results of this 1980 Special Adjustment along with the current status of the leveling data in DMA files are presented.

## 1. INTRODUCTION

Survey records for some 50,000 kilometers of geodetic leveling in Mexico and Central America are available at the Defense Mapping Agency Hydrographic/Topographic Center (DMAHTC). These data were observed in the 1946-72 period and are the result of cooperative mapping agreements with each country. Most of these leveling data were observed using first-order specifications by both personnel from the Inter American Geodetic Survey (IAGS) and from the country involved ( Skaggs 1979 ).

## 2. THE 1959 THROUGH 1972 ADJUSTMENTS

As the field observations were completed, they were furnished to DMA through IAGS, where the data were preprocessed and checked against accuracy specifications. Double run leveling was used for first-order work. The allowable discrepancy between forward and backward leveling between bench marks is  $4\text{mm}\sqrt{L}$ , where L is the distance in kilometers between bench marks. At DMA, the latitude for each bench mark was scaled from available map sources, and the observed leveling observations corrected for the effect of non-parallelism of equipotential surfaces (orthometric correction) based on normal gravity.

The leveling data were combined in regional blocks and adjusted by least squares as the data were received. These adjusted regional networks are shown in figure 1. The MX 1959 block (covering Mexico) and the PN 1959 block (covering Panama) were adjusted in the year 1959. Each new block was adjusted to fit the previously adjusted blocks. Most of the tidal stations along both coastlines were held fixed, continuing the method used in the adjustment of the leveling data in the United States and Canada in 1929. Although these elevations are adequate for controlling trigonometric leveling networks and large scale mapping projects they are not accurate enough for all modern engineering and scientific studies. Some level lines are warped by holding mean-sea-level at the tide gauges equal to zero. Thus the accuracy of leveling, observed using first-order procedures is downgraded by the adjustment procedure. An example of the networks

distortion can be seen, when we compare free adjustments verses adjustments where the mean-sea-level was held fixed at zero at the tidal stations.

<u>REGIONAL BLOCK</u>	<u>KILOMETERS</u>	<u>STANDARD ERROR OF UNIT WEIGHT FREE ADJUSTMENT</u>	<u>MSL FIXED</u>
CA 1960	6697	2.6	4.8
CA 1967	4786	2.5	3.5

The standard error of unit weight is calculated by Eq(3).

### 3. LEVELING DATA RECEIVED AFTER 1972

By 1972 most of the basic leveling networks had been completed. Regional block adjustments of these data by DMA had also been completed. Survey efforts by each country since 1972 has been in the form of extension and densification surveys. Re-leveling surveys have also been performed to keep the networks current. DMA continues to process leveling data only on a case-by-case basis since most of the countries have become self-sufficient. Approximately 10,000 kilometers of leveling data have been received at DMA since 1972 and these data have not been adjusted. These level lines are shown as broken lines in figure 1. A review of progress charts indicate another 7,000 kilometers of leveling data as being complete or near completion. These lines are shown as dotted lines in figure 1.

DMA's largest current effort in level processing is along the West Coast of South America, where the previous processed regional blocks are being combined into a single network and adjusted. New survey data are being processed and incorporated into this combined network. Preliminary results of this work have been published ( Bray 1977 ).

### 4. THE 1980 SPECIAL ADJUSTMENT

To provide a current evaluation of the leveling in Mexico and Central America, the previously processed level links from the regional adjustments were keypunched and assembled into a single simultaneous network adjustment. The network is continuous from 5 ties at the U.S.-Mexico border through Central America to Panama.

The network was adjusted by DMA using the computer program LEVEL ( Googe & Leroy 1970 ). Weights were assigned to the link observations based on distance. The a priori standard error for each link is played by the square root of the distance:

$$\sigma_i = \sqrt{L_i} \quad , \quad L_i \text{ is the link distance in km.} \quad (1)$$

and the observation weight:

$$P_i = 1 / \sigma_i^2 = 1 / L_i \quad (2)$$

The normal equations were inverted to provide error analysis upon completion of the least squares solution. The standard error of unit weight is calculated by the formula::

$$\sigma_o = \frac{\sum VPV}{m-n} \quad (3)$$

where:

- m = number of observations (links)
- n = number of unknowns (elevations)
- P = weight of observation
- V = least squares residual

First, the level links were combined into circuits and each loop closure checked against the  $4\text{mm}\sqrt{L}$  criterion, Six of the 72 circuits had closures over the allowable, however only one was significant. The circuit length is 274 kilometers with an allowable error of 66mm and a closure of 136mm. The reason for this discrepancy has not been found. A very large accumulation of systematic error is a possibility. The circuit also falls in an area of high seismic activity and land mass shifts during the leveling period is also possible. The line (E64 to E98), shown in figure 2 by the symbol  $\oplus$  was not used in the least squares adjustment. The average circuit distance in the network is 326 km. The average misclosure of circuits is  $1.9\text{mm}\sqrt{P}$ , where P is the perimeter distance for the circuit.

A least squares adjustment of the links was performed holding only one station fixed, Bench Mark A 680 at the U.S. - Mexico border. The standard error of unit weight from the adjustment was  $2.3\text{mm}\sqrt{L}$ . A statistical analysis of the residuals from the adjust-

ment are given in Table 1. Nine normalized residuals out of the 246 links were flagged as falling over 3.0. The normalized residuals ( $V\sqrt{P}$ ) are plotted against the Gaussian normal distribution curve for convenience. The actual distribution curve is shown in Table 1. It departs from the normal curve in the 0.2 to 0.8 increment range. The average link correction from the least squares adjustment was 9mm. As seen in figure 2, there is a large difference in the length of each link. The average link correction when related to the distance was  $1.0\sqrt{L}$ , L is the link distance in kilometers.

The standard error of the computed elevations from the free adjustment propagate from zero at Bench Mark A 680 in the United States, which was held fixed, to a maximum of 121mm at bench marks in Eastern Panama. These adjusted differences in elevation were used together with the spur line differences to the tidal stations, to determine the relative heights of local mean-sea-level along both coastlines. After the adjustment the elevations were all uniformly shifted to Port Isabel, Texas so it would be -0.23 meters and correspond to the 1963 Special Adjustment by NGS (Braaten & McCombs 1963). The local mean-sea-level variations, indicated by this 1980 Special Adjustment, and selected relative errors between the tidal bench marks are given in figure 2. Notice that the mean-sea-level on the Pacific seems to be about 2 decimeters higher than mean-sea-level on the Gulf and Caribbean Sea side. In the United States the mean-sea-level on the Pacific Coast was found to be about 6 decimeters higher than mean-sea-level on the Atlantic Coast.

Adjustments of the overall net, by constraining the tidal bench marks with varying weights (based on the tidal observation periods), resulted in adjustments with the standard error of unit weight ranging from 3.9 to 5.8. This increase in  $\sigma_u$  is caused by the difference in height of mean-sea-level at the two Coasts. The network is forced to tilt by these constraints. A better solution would be to constrain the differences in elevations between tidal bench marks.

## 5. THE NORTH AMERICAN REDEFINITION

The need for a redefinition of the vertical reference system in Mexico and Central America is desirable. The present vertical system, referenced to mean-sea-level will not meet all of the requirements of future surveying and scientific needs. New leveling observations will have difficulty in fitting the previously determined elevations. Almost as important as the method of adjustment is the upgrading of the network, which can be accomplished by applying refined leveling corrections that have not previously been applied ( Holdahl 1979 ). The refraction correction should be applied to correct for the bending of the optical ray path. The astronomic correction can be applied to account for the tilting of the equipotential surfaces, relative to the terrain, caused by the changing positions of the sun and moon. The effect of real gravity has also not been taken into account in the previous adjustments. To correct for the effect of non-parallelism of equipotential surfaces, the orthometric correction was applied based on normal gravity. Observed gravity data does exist for most of the leveling in Mexico and Central America. The significance of these refinement corrections, as they would apply to Mexico and Central America network, is under study at DMA.

## 6. CONCLUSIONS

The basic leveling network in Mexico and Central America was observed using first-order field procedures. The network is continuous from the Mexico-United States border to Panama. Although the results of this 1980 Special Adjustment show some departure from expected first-order results, the net could be upgraded by applying the refraction, astronomic, and true gravity corrections.

Participation in the redefinition of the North American Vertical Datum by each country will have many rewards. Automation of the survey observations will allow the network to be upgraded

by eliminating known systematic errors in the net. Possibly more important, is the future use of the data by scientists. As new leveling data are observed, vertical crustal motion and rates of elevation change can be determined by comparison with an existing data bank of information in automated format.

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TABLE 1

STATISTICAL ANALYSIS OF RESIDUALS

FROM THE DMA 1980 SPECIAL ADJUSTMENT OF MEXICO AND CENTRAL AMERICA

RESIDUALS  
 -----  
 N = ..... 246  
 RANGE = ..... 114.670  
 MIN = ..... -59.633  
 MAX = ..... 56.137  
 MEAN = ..... .431  
 AVERAGE = ..... 6.569  
 VARIANCE = ..... 169.642  
 STD DEV = ..... 13.032

NORMALIZED RESIDUALS  
 -----  
 N = ..... 246  
 RANGE = ..... 7.073  
 MIN = ..... -3.515  
 MAX = ..... 3.557  
 MEAN = ..... .009  
 AVERAGE = ..... .925  
 VARIANCE = ..... 1.600  
 STD DEV = ..... 1.265  
 SKEWNESS = ..... -.007  
 KURTOSIS = ..... 3.231

NO. PLUS SIGNS = ..... 128  
 NO. MINUS SIGNS = ..... 114

NO. PLUS SIGNS = ..... 126  
 NO. MINUS SIGNS = ..... 114

COMPARISON WITH NORMAL SAMPLE (STATISTICS AND PLOT)

INTERVAL ACTUAL NORMAL \* PLOT OF NORMAL DISTRIBUTION CURVE

INTERVAL	ACTUAL	NORMAL	* PLOT	OF	NORMAL	DISTRIBUTION	CURVE
BELOW -3.0	4	0	0	4	RESIDUAL(S) ARE OUT OF RANGE		
-3.0 TO -2.5	2	0	0	2			
-2.5 TO -2.0	0	0	0	0			
-2.0 TO -1.5	0	0	0	0			
-1.5 TO -1.0	4	1	1	4			
-1.0 TO -0.5	4	2	2	4			
-0.5 TO 0.0	3	3	3	3			
0.0 TO 0.5	6	4	4	6			
0.5 TO 1.0	8	6	6	8			
1.0 TO 1.5	3	8	8	3			
1.5 TO 2.0	15	10	10	15			
2.0 TO 2.5	12	13	13	12			
2.5 TO 3.0	9	15	15	9			
3.0 TO 3.5	11	17	17	11			
3.5 TO 4.0	12	18	18	12			
4.0 TO 4.5	15	19	19	15			
4.5 TO 5.0	25	19	19	25			
5.0 TO 5.5	14	18	18	14			
5.5 TO 6.0	17	17	17	17			
6.0 TO 6.5	15	15	15	15			
6.5 TO 7.0	14	13	13	14			
7.0 TO 7.5	6	10	10	6			
7.5 TO 8.0	9	8	8	9			
8.0 TO 8.5	7	6	6	7			
8.5 TO 9.0	7	4	4	7			
9.0 TO 9.5	5	3	3	5			
9.5 TO 10.0	4	2	2	4			
10.0 TO 10.5	1	1	1	1			
10.5 TO 11.0	3	0	0	3			
11.0 TO 11.5	0	0	0	0			
11.5 TO 12.0	5	0	0	5	RESIDUAL(S) ARE OUT OF RANGE		
ABOVE 12.0	5	0	0	5			

LISTING OF NORMALIZED RESIDUALS OVER : 3.0  
 -----  
 (FROM) DESIGNATION (TO) DESIGNATION (V) (P) (VSGP)

PN V40	PN H47	26.0	.0140	3.1
PN S2-4-1	PN S2	-4.9	.3817	-2.0
P100	P169	-30.7	.0113	-3.3
A174	576	19.6	.0324	3.5
2A59	A174	20.9	.0238	3.2
C13	C59	-31.6	.0124	-3.5
G-17	R-14	35.0	.0079	3.1
S15	J-37	-27.9	.0140	-3.3
M E-19	M F-128	36.2	.0096	3.6

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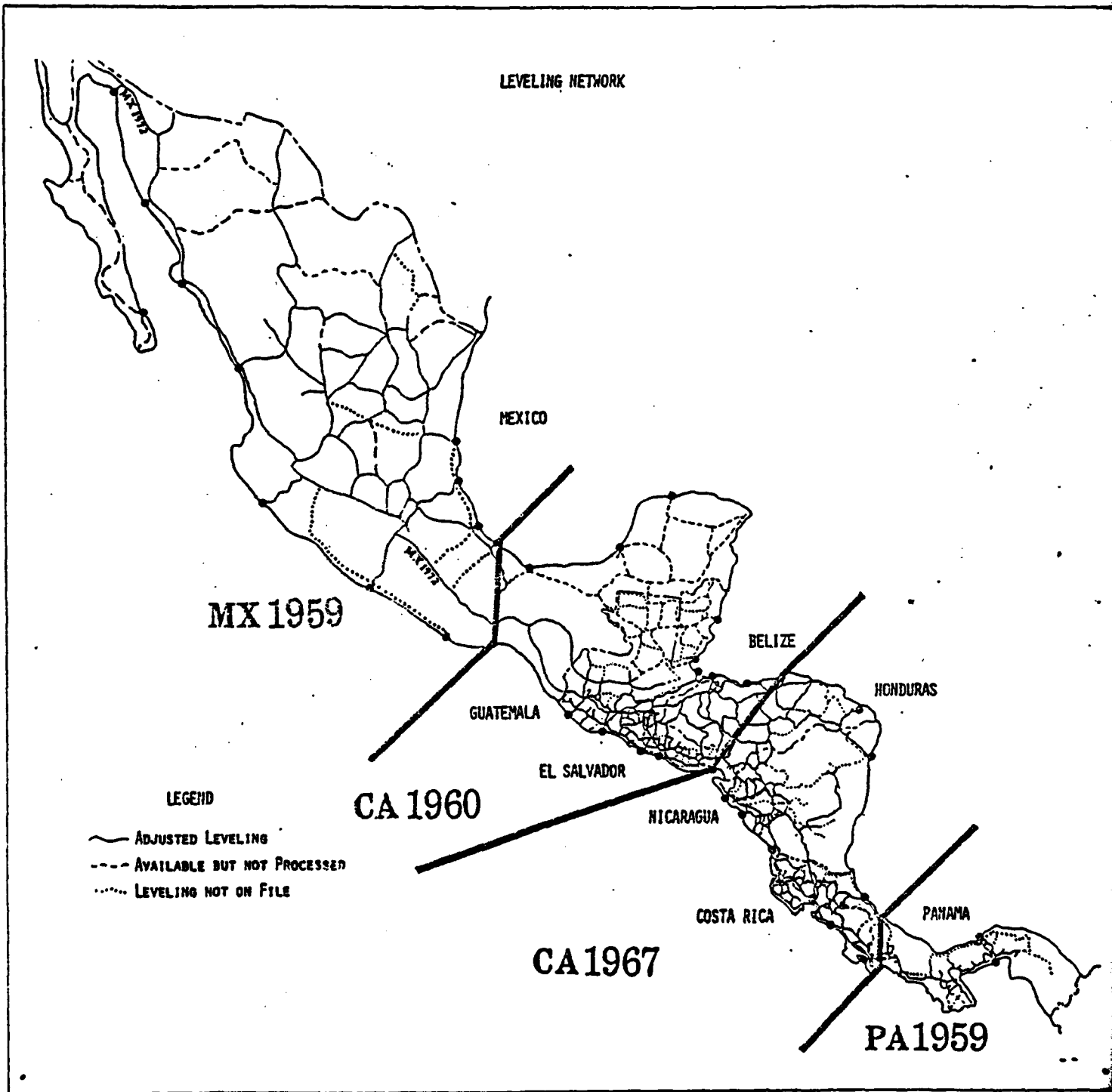
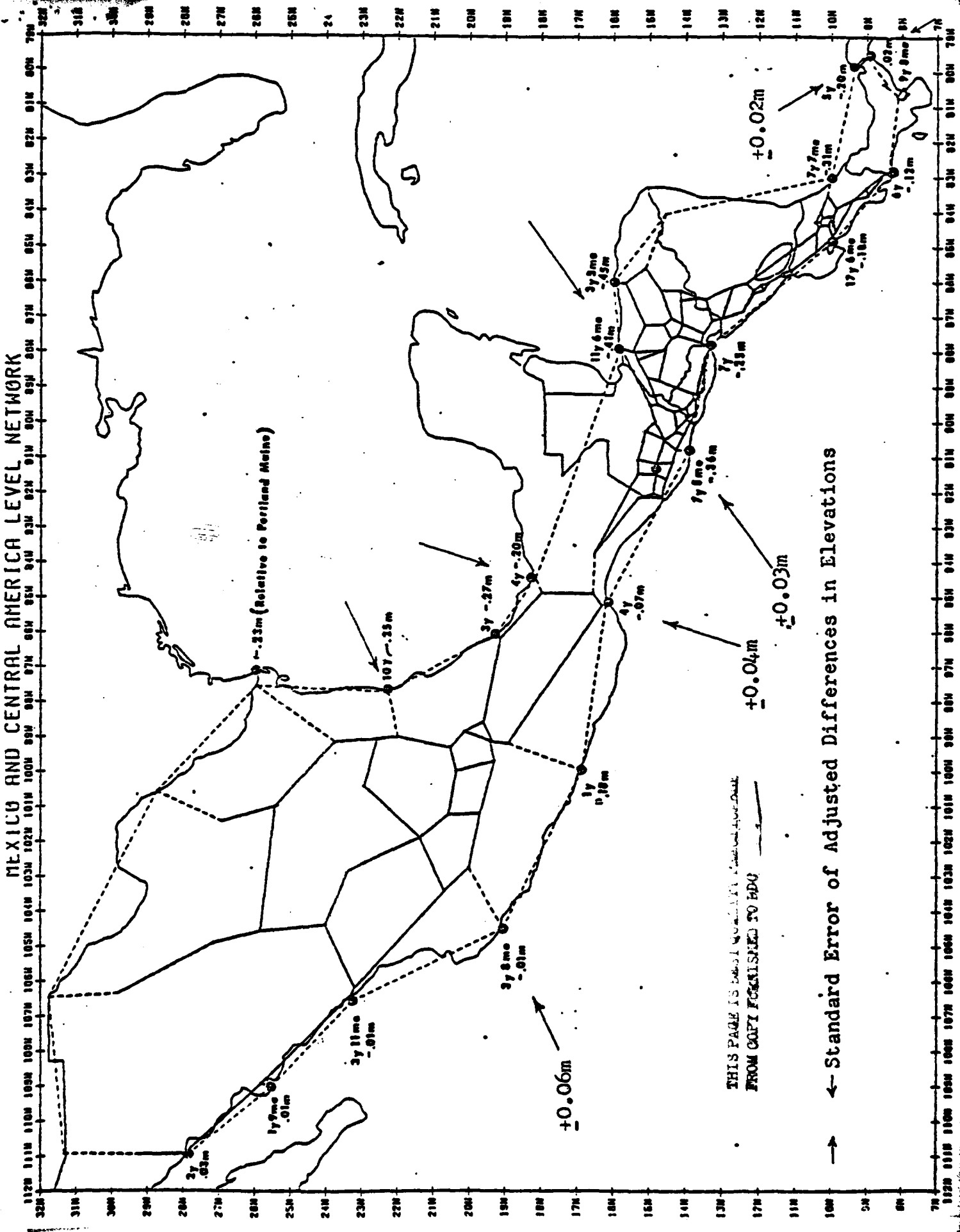


FIGURE 1: STATUS OF THE LEVELING DATA FOR MEXICO AND CENTRAL AMERICA

MEXICO AND CENTRAL AMERICA LEVEL NETWORK



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← Standard Error of Adjusted Differences in Elevations