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16. ABSTRACT

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An experimental wind screen was installed on a mountain bridge where truck trailers had been overturned by sporadic gale force side winds. The 10-foot high screen was made of 9 gauge galvanized steel chain link mesh fencing with all of the apertures filled with vertically placed crimped aluminum slats. The spaces between the slats resulted in a porosity of 20 percent. The screen has been completely successful in preventing either the overturning of vehicles or loss of driver control during a two year test period. The report suggest other types of locations that may benefit from wind protection and offers basic design considerations.

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HIGHWAY RESEARCH REPORT

WIND SCREEN SUBDUES GALE FORCE WINDS ON A MOUNTAIN BRIDGE

INTERIM REPORT

69-12

STATE OF CALIFORNIA

TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 636357

Prepared in Cooperation with the U.S. Department of Transportation, Bureau of Public Roads January, 1969

STATE OF CALIFORNIA—TRANSPORTATION AGENCY
RONALD REAGAN, *Governor*

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD., SACRAMENTO 95819

November 1968
Interim Report
M & R No. 636357-1

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

WIND SCREEN SUBDUES GALE FORCE WINDS

ON A MOUNTAIN BRIDGE

ERIC F. NORDLIN
Principal Investigator

LOUIS BOURGET
Co-Principal Investigator

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

ABSTRACT

REFERENCE: Nordlin, Eric F. and Bourget, Louis, "Wind Screen Subdues Gale Force Winds on a Mountain Bridge". State of California, Department of Public Works, Division of Highways, Materials and Research Department. Research Report 636357-1, November 1968.

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KEY WORDS: Bridges/structures, protection, vehicles, wind, windbreaks.

ACKNOWLEDGEMENTS

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This paper reports on work performed under Research Project B-1-24, conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads. The opinions, findings, and conclusions are those of the authors and not necessarily those of the Bureau of Public Roads.

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WIND SCREEN SUBDUES GALE FORCE WINDS ON A MOUNTAIN BRIDGE

SYNOPSIS

"Everybody talks about the weather but nobody does anything about it." - - Mark Twain.

This paper discusses a method of preventing vehicular highway accidents caused by high velocity crosswinds that are known to occur in California and various parts of the world. Dangerous conditions are often developed in mountainous or undulating terrain where motor vehicles are suddenly exposed after emerging from the protection of earth cuts or embankments.

The protecting device is an experimental wind screen made of chain link mesh fencing, fabricated from 9 gauge galvanized steel wire. All of the apertures are filled with vertically placed crimped aluminum slats. The spaces between the slats yield a porosity of about 20 percent.

The experimental wind screen was installed on a relatively new, 2-lane, high elevation freeway bridge across a mountain ravine. The screen extends 8 feet above the 2 foot high concrete parapet of the bridge barrier rail, giving a total height of 10 feet above the pavement.

Before the wind screen was installed, the winds sometimes reached velocities that could overturn large truck trailers and often produced forces that impaired driver control of other vehicles. This condition made it necessary to restrict truck traffic during each period that high winds were developed.

After the wind screen was installed, the hazard of the crosswind was eliminated. Some low velocity headwinds now find a protected path along the bridge behind the wind screen but have not been a problem. These are the only winds that can now be measured anywhere on the bridge because the filtered crosswinds are now below the level of the head winds.

Instrumentation for and analysis of wind data are described along with recommendations as to procedure for adaption of design ideas to other locations.

I. THE PROBLEM

A new four-lane divided freeway, U. S. Interstate Route 8, is replacing the older two-lane highway, U. S. 80, between San Diego and El Centro, California.

Most of the westbound lanes of the new freeway were completed first in the Laguna Mountain area to give the motorist a safer high level route with less turns and hazards from falling rock. To this end, some of the newly completed westbound lanes were temporarily required to handle both east and westbound traffic while work continued on the unfinished eastbound lanes (Figure 1).

The two-way use of the westbound lanes began in December 1963 and continued while a few comments of strong but sporadic westwinds came in from various sources. These comments were dramatically verified on April 2, 1964, when two truck and trailer combinations traveling in the westbound lane had their trailers overturned on Devils Canyon Bridge No. 1, between 0130 and 0230 in the morning (Figures 2 and 3). This bridge runs from north to south, and west winds are at normal incidence. The bridge was completely blocked by the overturned vehicles in two separate places and all traffic was halted for over 10 hours. Fortunately, there were no human injuries, and the California Highway Patrol was able to prevent any collisions with the trucks and trailers. The portent of accidents of greater severity was very clear. Either a collision or crushing accident could have occurred had any other vehicles been in the eastbound lane. Had the trucks been traveling in the eastbound lane, the trailers would likely have toppled over the barrier rail. After this accident, the California Division of Highways and the California Highway Patrol jointly assumed the responsibility to restrict truck and camper traffic during too frequent periods of high winds.

II. RESEARCH METHOD

A. GENERAL

Plans were initiated to measure separately and simultaneously the winds on the bridge and in a free wind area. These measurements were to be made over long time intervals to yield reference values "before and after" the placement of a wind screen. The plan seemed entirely feasible but nature managed to inject one unforeseen variable -- the head wind mentioned in the Synopsis.

Another aspect of the plan was to identify other hazardous locations in the general area that might need similar wind protection. This part of the program is continuing.

B. INSTRUMENTATION

The remote bridge location had no electrical power, and most long interval recording anemometers are A.C. operated devices. A search was made for a wind recording instrument that could operate for a period of about 2 months unattended. The answer was found in Model 1071, Mechanical Weather Station, available from Meteorological Research Incorporated, Altadena, California. These instruments will record wind velocity, direction, and temperature for a period of 8 weeks and require only two D cells to power the clock for the calibrated chart drive system.

The velocity information records continuously but is most accurately presented as average wind speeds for hourly intervals. Maximum peak velocities can be approximated by multiplying any one hour average mph by 1.6. Note: It is common practice[2] to multiply a 5 minute average mph by 1.5 on higher speed recorders, so 1.6 seems conservative for an hourly average K factor.

C. WIND SCREEN

The Bridge Department of the California Division of Highways initially furnished preliminary designs for a wind screen made of chain link mesh fencing and aluminum slats, for all but the topmost portion where horizontal louvers were considered as an upward deflecting mechanism. The louver idea was eventually discarded in favor of relying on the air turbulence that would develop at the face of the wind screen to provide any extra lift required. This later proved to be a sound and economical decision. The higher the wind speed, the greater the lift. During high winds the extra lift varies from 2 to 3 feet above the top edge of the screen.

Figures 4 through 7 show Devils Canyon Bridge No. 1 before and after erection of the wind screen. Figure 8 shows the details of the wind screen.

The slatted fence is one of the old reliable devices for protection from either snow or wind. It is also very efficient. A ten foot high all metal slatted fence has successfully protected citrus trees that do not have their roots in soil. These trees are hydroponically nourished. Their roots dangle into a saturated atmosphere in large tanks, and the trunks are supported by large cushioned clamps. The site is the Citrus Experimental Station on the University of California campus at Riverside, where sporadic winds sometimes exceed 40 mph.

Dr. H. B. Schultz, at the University of California, College of Agricultural Engineering at Davis, has found that a wood slatted fence with a porosity of 25 percent can reduce free winds to 0.4 or less within four fence heights on the lee side. A 50 percent porosity is very nearly as good[1].

When the Bridge Department furnished preliminary designs for an all metal wind screen made of chain link fencing and aluminum slats, they were unaware of the above examples but in good company.

The reduction of bridge crosswinds to about one-half of the velocity of the free winds seemed a reasonable objective as this would reduce the side forces to about one-fourth of the unprotected condition, based on:

$$G \cong \left(\frac{V}{20}\right)^2 \qquad \text{Where } G = \text{psf}, \quad V = \text{mph}$$

III. MEASUREMENT

A. INSTRUMENT PLACEMENT

Wind measurements were begun on October 19, 1965, in two places: on the bridge at a height of 9 feet above the paved deck and at 40 feet below the bridge on a windswept ledge (Figure 9). The first tests continued through mid April 1966. The free wind reference site below the bridge gave no signs of interfering turbulence from the structure during any of the long term tests. The tests "before" a wind screen was installed continued for over 6 months. West winds showing hourly averages of 18 or more miles per hour at the "free wind site" were considered significant for reducing the data. None of the east winds ever exceeded 16 mph.

The wind screen was completed in September 1966, and a second set of measurements covered the period between October 19, 1966, through April 1967. This is almost exactly the same seasonal time period as for the first tests, but one year later.

B. RESULTS BEFORE WIND SCREEN

The following Table 1 summarizes the predominant west cross-wind data recorded at the two instrumentation locations during the recording period prior to installation of the wind screen along the west side of the bridge. Figure 10 shows chart samples from the wind measuring instruments at the two locations prior to the wind screen installation.

TABLE 1

WEST CROSS WINDS BEFORE INSTALLING SCREEN

	Free Winds 40' Below Bridge	Bridge Winds 9' Above Deck
Total range recorded 6 mo. hourly averaged	0-52 mph (est.)	0-47 mph lee side 0-49 mph windward
Ratio Bridge Winds/ Free Winds	Ref. = all winds over 18 mph avg.	.85 ± lee side .95 ± windward
Max. Hourly Avg.	52 mph (est.)	47 mph lee side 49 mph windward
Highest Peak Velocity Est. = 1.6 x Max. Hourly Avg.	83 mph	75 mph lee side 78 mph windward
* Critical Region for Vehicles, Hourly Avg.		30 to 35 mph

*The critical crosswind speed hourly average is based on the probability of crosswind gusts in excess of 50 mph being developed on the bridge.

C. RESULTS AFTER WIND SCREEN

Some salient comments must be made before reporting the wind data obtained after the wind screen was installed. The crosswinds are no longer measurable on the bridge due to some low velocity south head winds that now find a protected path behind the wind screen for the full length of the bridge. The south head winds have replaced the damaging west crosswinds as the predominant wind on the bridge. The highest head wind velocity measured over a 6 month period was an hourly average of 23 mph. The crosswind that filters through the screen is completely turned within one inch of the screen surface and merges with the head wind. It is estimated that the screen is reducing the crosswind to about 0.35 of the free west wind velocity. A comparison of the south head winds on the bridge after erection of the wind screen and the west free winds is shown for informational value in the following Table 2. Figure 11 shows chart samples from the wind measuring instruments at the two locations after the wind screen installation.

TABLE 2

FREE WEST WINDS - SOUTH HEAD WINDS

AFTER INSTALLING SCREEN

	Free West Winds 40' Below Bridge	South Head Winds 9' Above Deck
Total Range Recorded 6 mo. Hourly Averaged	0-43.5 mph	0-23 mph
Ratio Head Winds/ Free West Winds	Ref. = all winds over 18 mph avg.	.53 ±
Max. Hourly Avg.	43.5 mph	23 mph
Highest Peak Velocity Est. = 1.6 x Max. Hourly Avg.	70 mph	37 mph

It is important to note that the head winds have not proved hazardous over a trial period of 24 months. Large vehicles are no longer restricted from traveling the westbound lanes of U. S. Interstate Route 8 because of winds.

IV. PROBE TESTS

Some special probe tests were conducted across the bridge, first with a small wind flag mounted on a long pole and later with a 15 foot pole having alternate short and long ribbons spaced one foot apart. These tests were helpful in explaining the baffling change in wind direction on the bridge after the screen was installed.

A. SOURCE OF HEAD WINDS

Some of the strong west winds over the entire area find a spillway beyond the south pass of the bridge. The contours of the terrain at this location reduce and deflect the west wind to a half velocity head wind that filters through the south gap traveling north on the bridge (Figure 12). This head wind was readily turned by the predominant west crosswind on the bridge before the screen was installed and no evidence of a head wind appeared on the wind instruments mounted near the center of the bridge (Figure 13). After the screen was installed, the west crosswind was so drastically reduced that the south head wind became the predominant wind measured on the bridge.

B. LIFTING OF CROSSWINDS

Wind flag probes were also valuable in disclosing the beneficial lifting of the crosswinds as a result of the turbulence produced on the windward face of the screen. The amount of wind lift varies with the wind speed thus producing a higher zone of protection when it is most needed for tall trucks during strong wind gusts. Typical values of extra wind lift varied from 20 to over 30 percent higher than the wind screen itself during the tests. This extra lift was sustained across the entire 37 foot width of the bridge (Figures 14, 15, and 16).

The result of two years of experience with the low velocity head winds on the bridge since the wind screen was installed is that they are completely free from side vector and seem to act more as a stabilizing force to prevent the waggle of trailers.

It seems important to observe that some of the most valuable information was disclosed with very simple wind flag devices as a supplement to the more sophisticated wind recording instruments.

V. RECOMMENDATIONS

The accident reducing possibilities offered by wind screens appears to have more merit than may have been recognized thus far in highway planning. The greatest need usually exists wherever recurrent or persistent crosswind leads to inadequate driver control or the overturning of vehicles. Some hazardous situations may be difficult to anticipate but others are fairly obvious. These include bridges across mountain ravines, elevated highways that cut straight through undulating topography where protection alternates with exposure, and on long downgrade curves where vehicles first receive tail winds and then turn broadside to the wind forces.

The requirements for a wind screen are fairly broad: a height of about 10 feet with respect to the pavement at its highest point; a dependence upon no more than five fence heights laterally in the protected zone, at this stage of experience; and a porosity between 20 and 50 percent at the option of the engineer. The lower percentage values probably give more wind lift but experience more wind loading on the screen.

The slatted chain link mesh fence seems to be one of the most economical ways of producing the properties desired.

VI. REFERENCES

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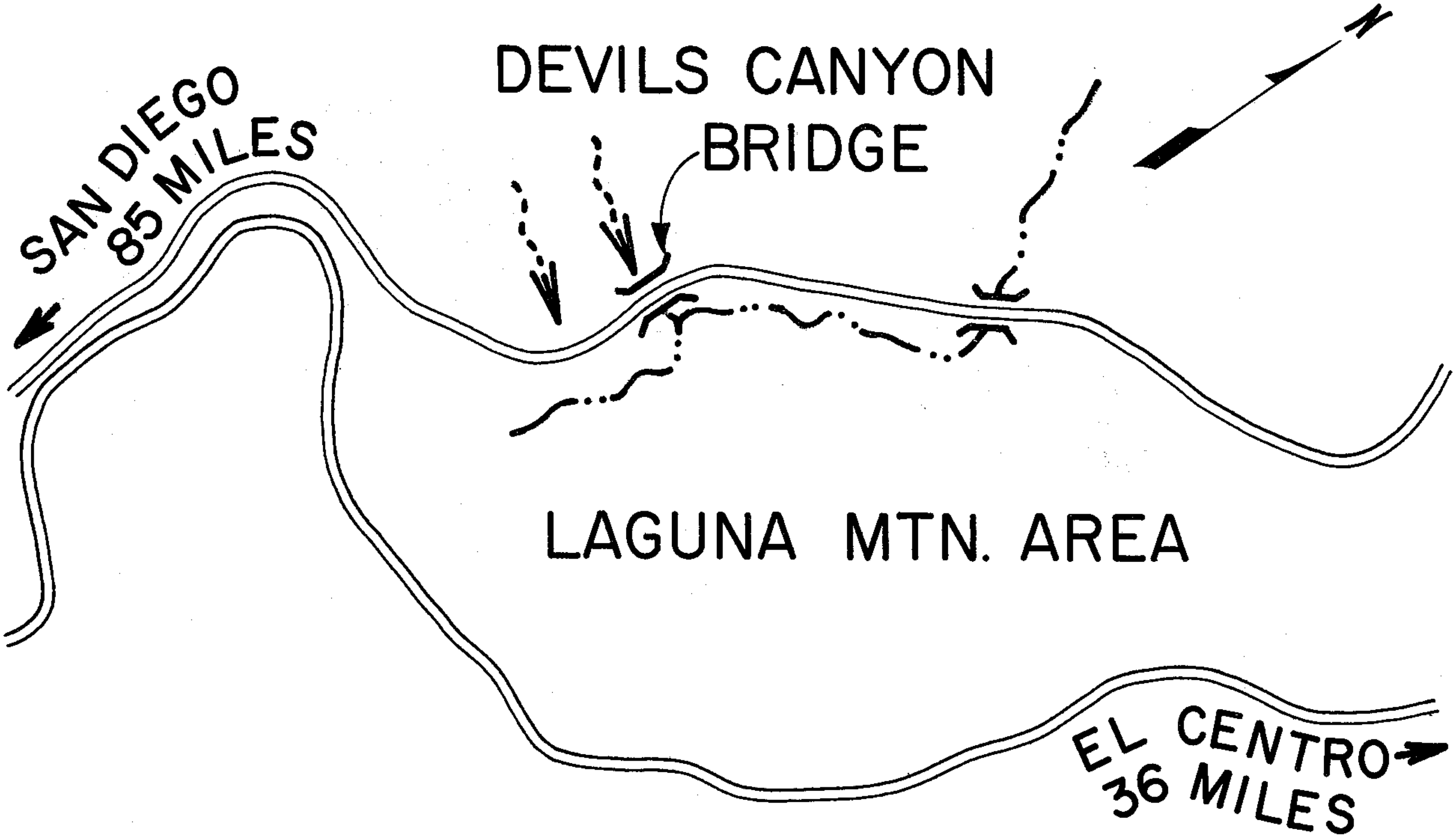
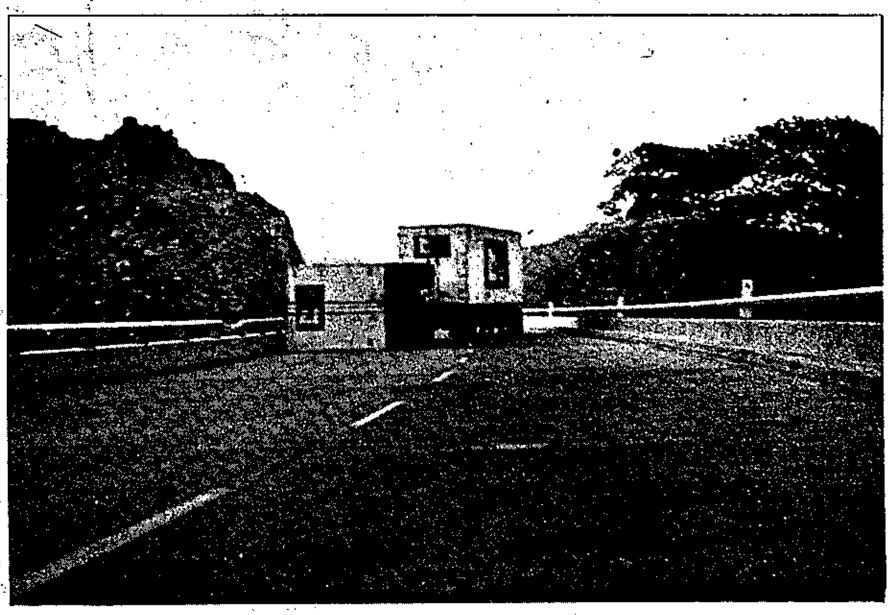

DEVILS CANYON
BRIDGE
SAN DIEGO
85 MILES
LAGUNA MTN. AREA
EL CENTRO
36 MILES
N

FIGURE 1



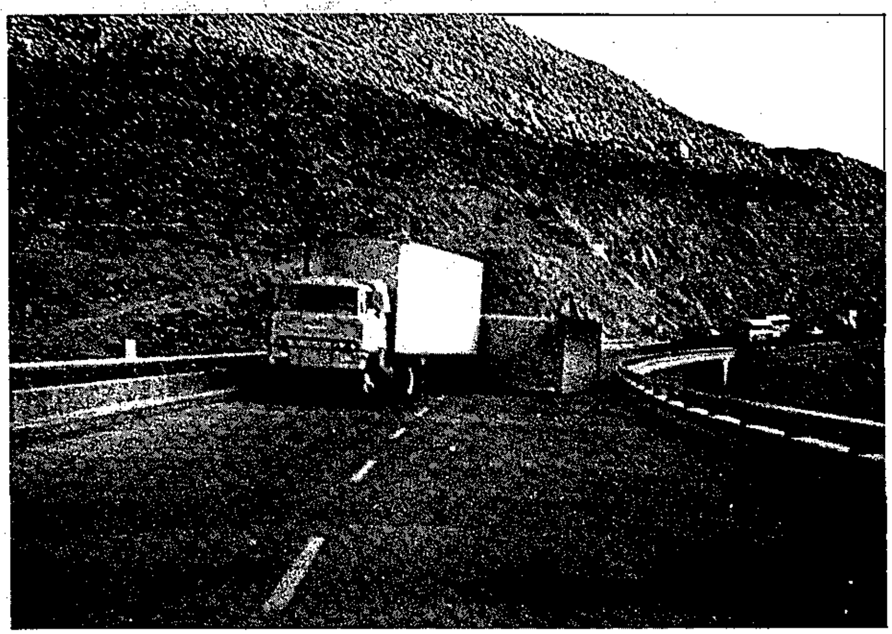


FIG. 2 TWO LARGE TRUCK TRAILERS BLOWN OVER WITHIN 30 MINUTES. 0145 AND 0215, APRIL 2, 1964.

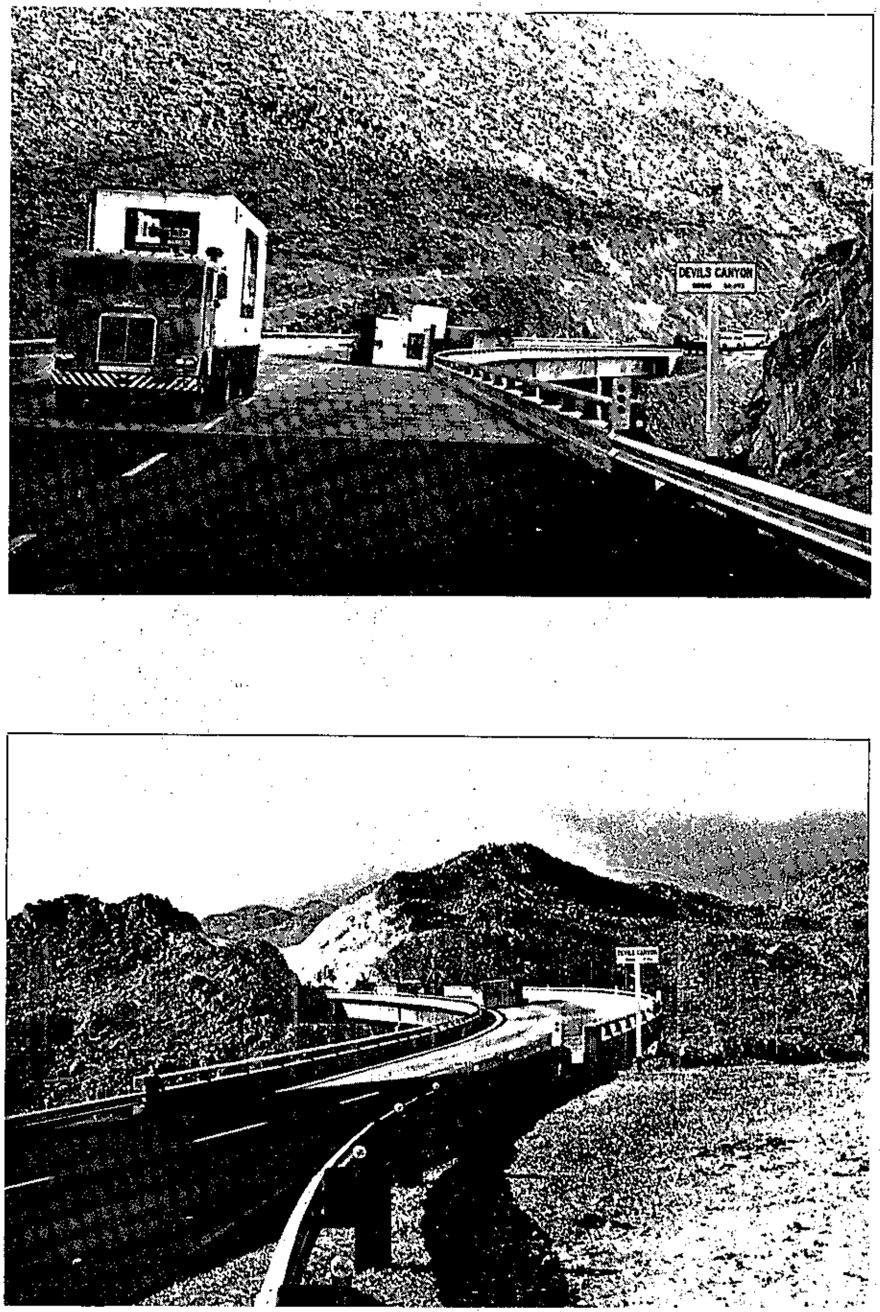


FIG. 3 THE HIGHWAY WAS CLOSED FOR MORE THAN 10 HOURS

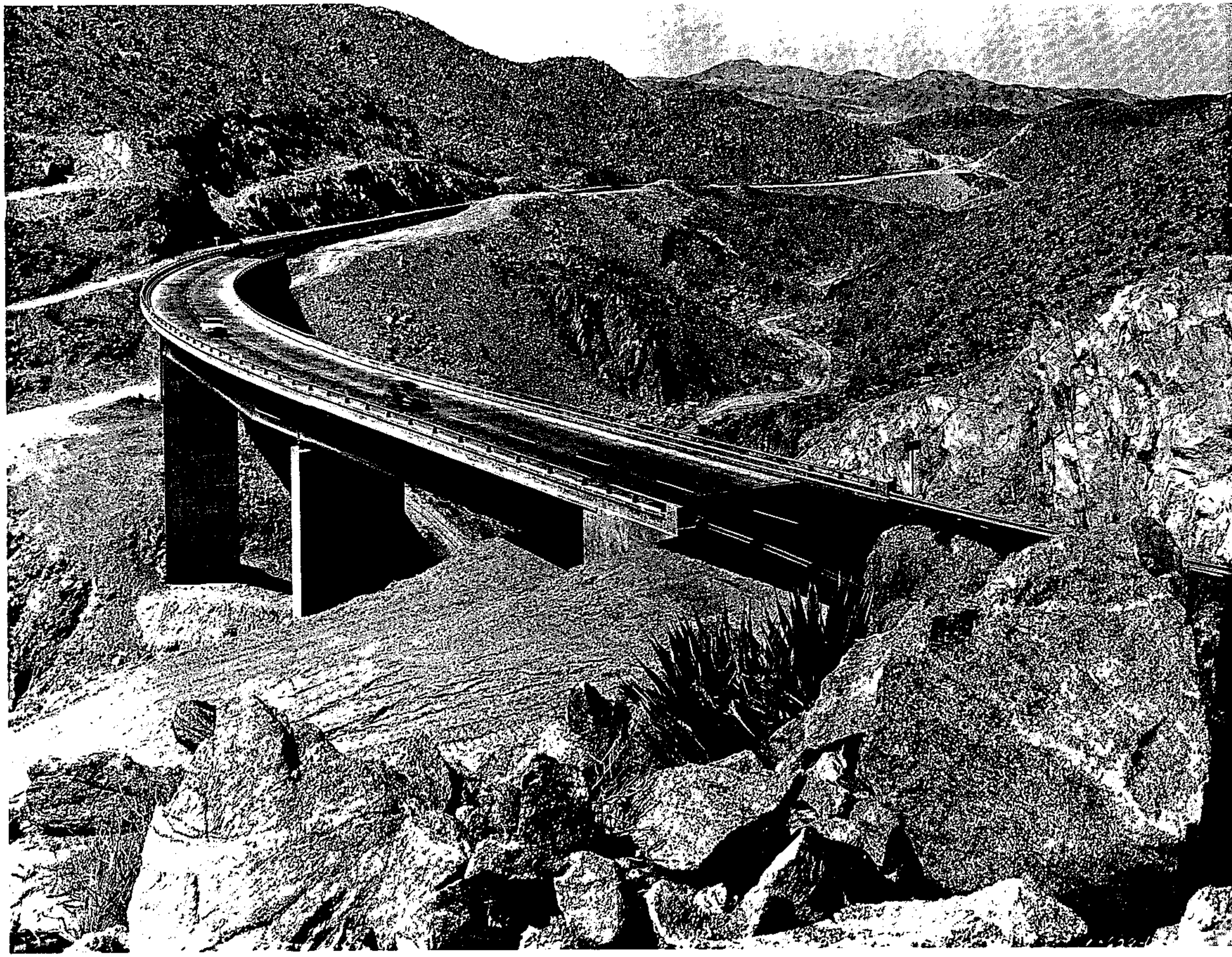


FIGURE 4 VIEW TO NORTH -- BEFORE WIND SCREEN

FIGURE 5 VIEW TO NORTH -- AFTER WIND SCREEN

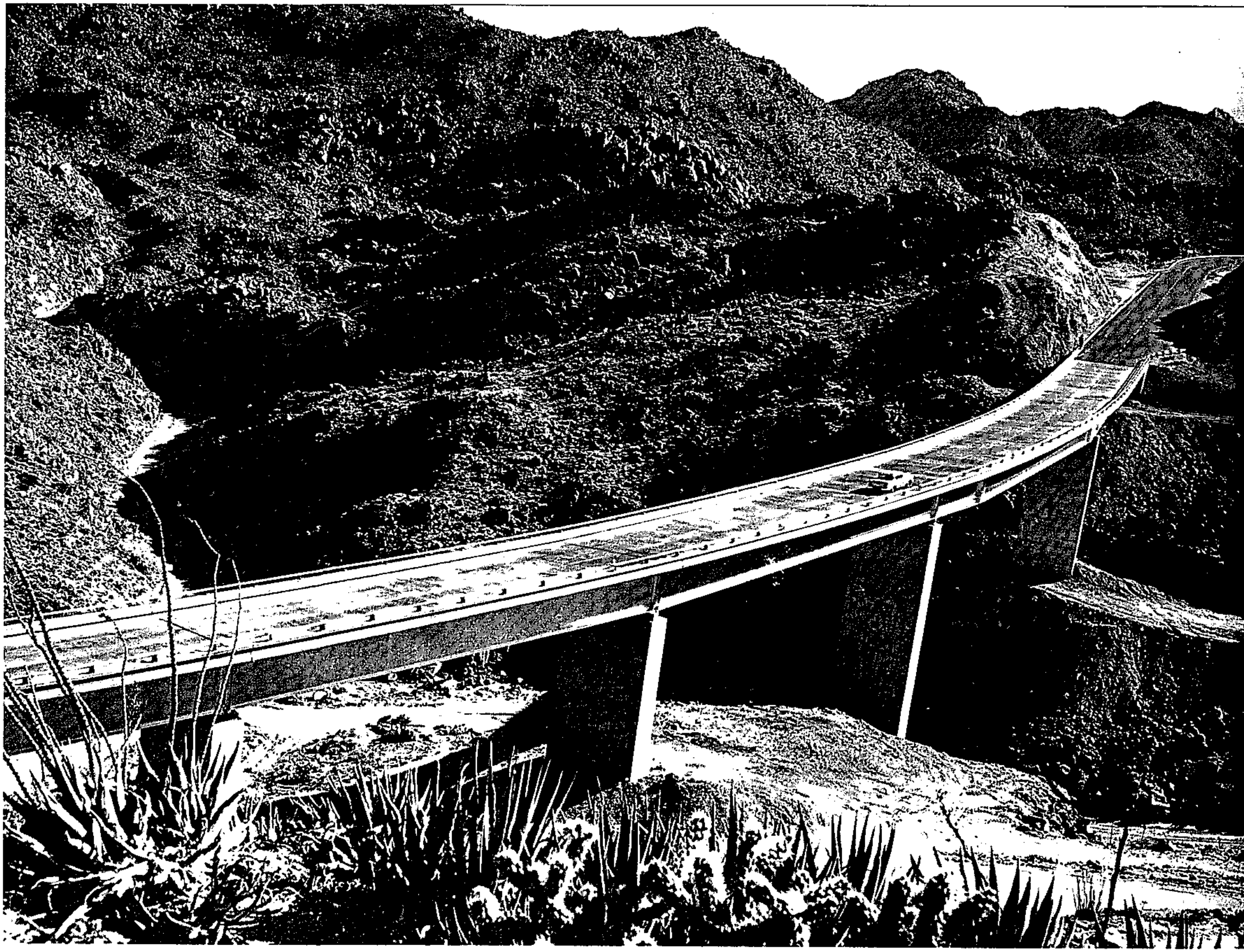


FIGURE 6 VIEW TO SOUTH -- BEFORE WIND SCREEN

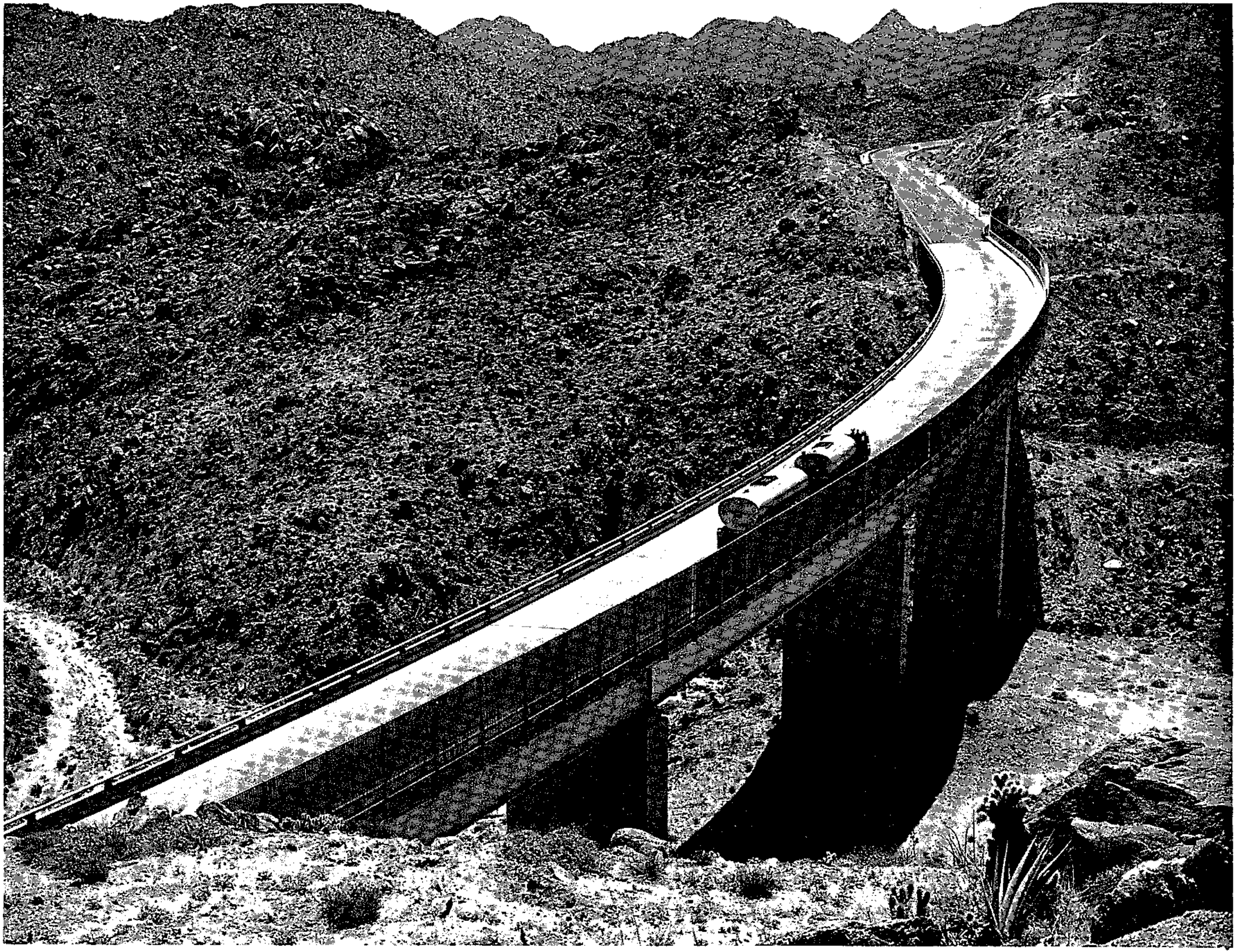
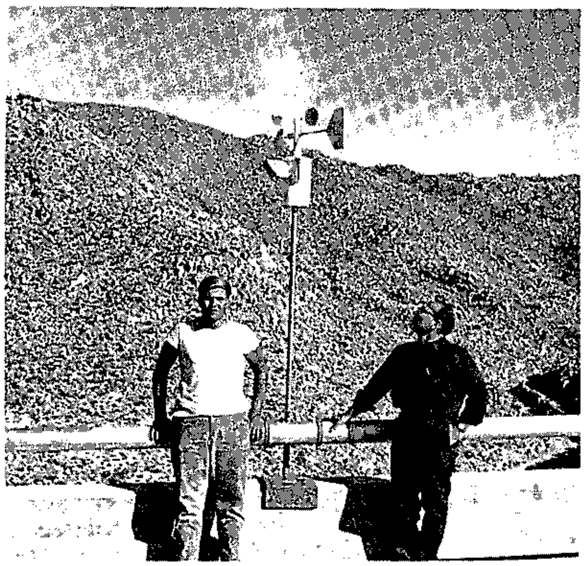


FIGURE 7 VIEW TO SOUTH -- AFTER WIND SCREEN



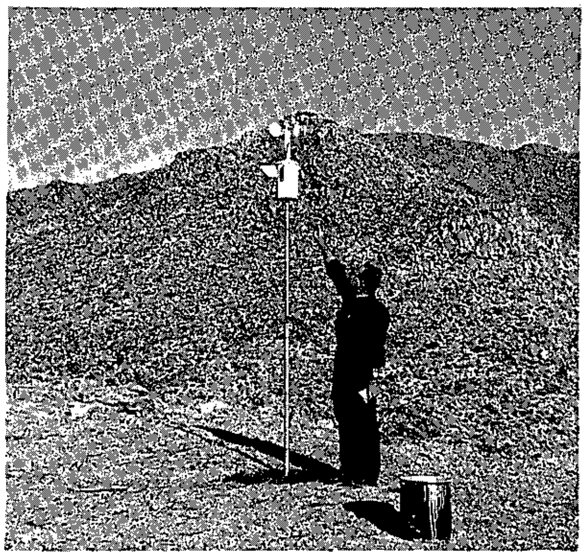


FIGURE 9 WEATHER STATIONS -- 9' ABOVE DECK AND 40' BELOW THE BRIDGE

BEFORE WIND SCREEN

9' ABOVE DECK
21 TO 47 MPH
WEST WINDS

FREE WINDS

40' BELOW BRIDGE
28.5 TO 52 MPH
WEST WINDS

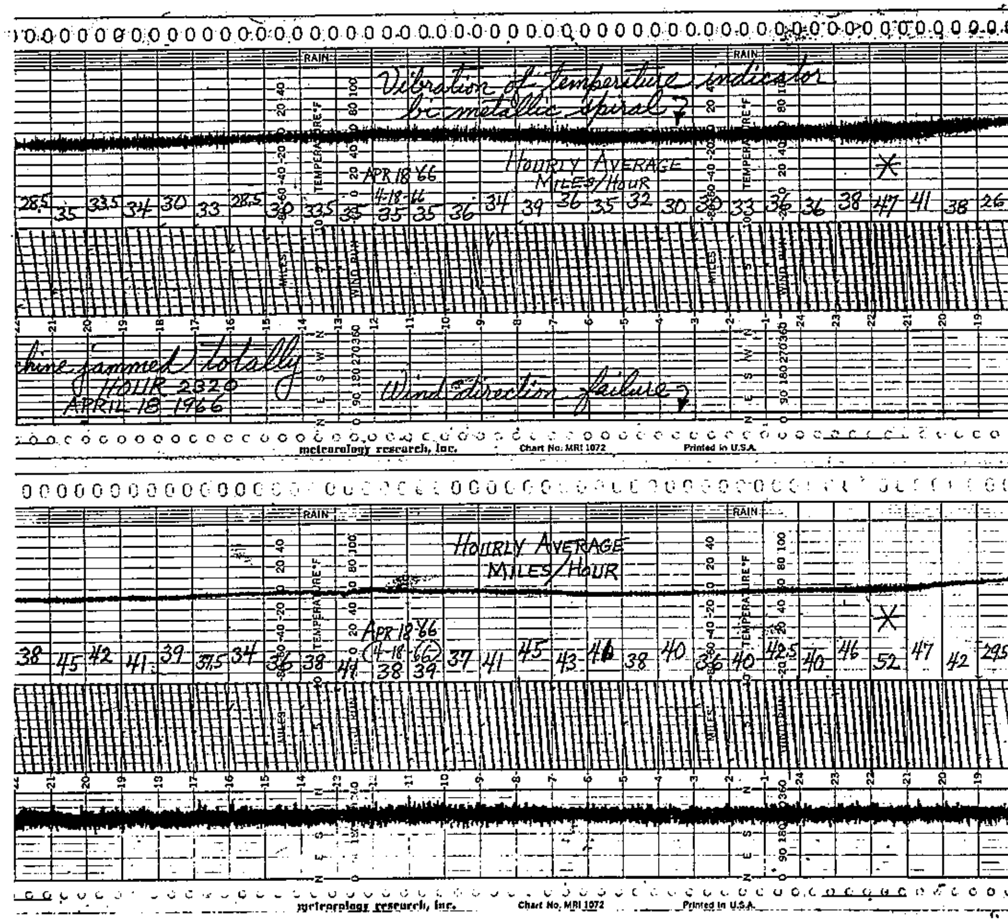
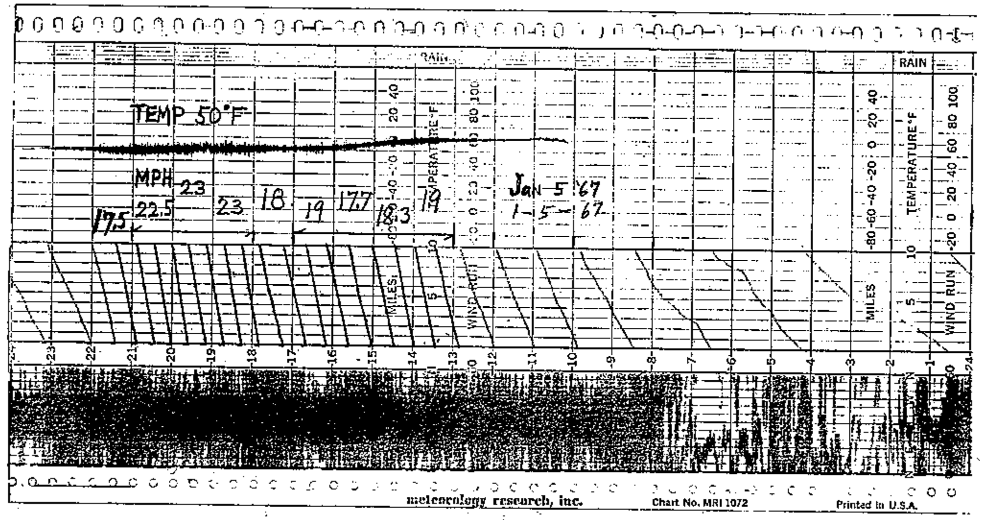


FIGURE 10 WIND CHART SAMPLES - BEFORE WIND SCREEN

AFTER WIND SCREEN

9' ABOVE DECK
18 TO 23 MPH
SOUTH HEADWINDS



FREE WINDS

40' BELOW BRIDGE
32 TO 43 MPH
WEST CROSSWINDS

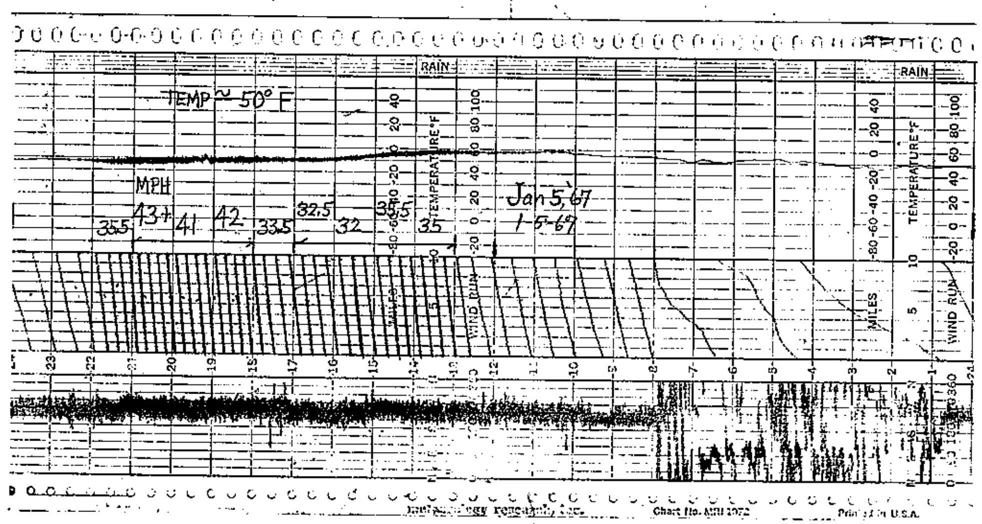


FIGURE 11 WIND CHART SAMPLES -- AFTER WIND SCREEN

FIGURE 12 DIRECT WESTWINDS CAUSE STRONG CROSSWINDS
DEFLECTED WESTWINDS CAUSE LESSER HEADWINDS

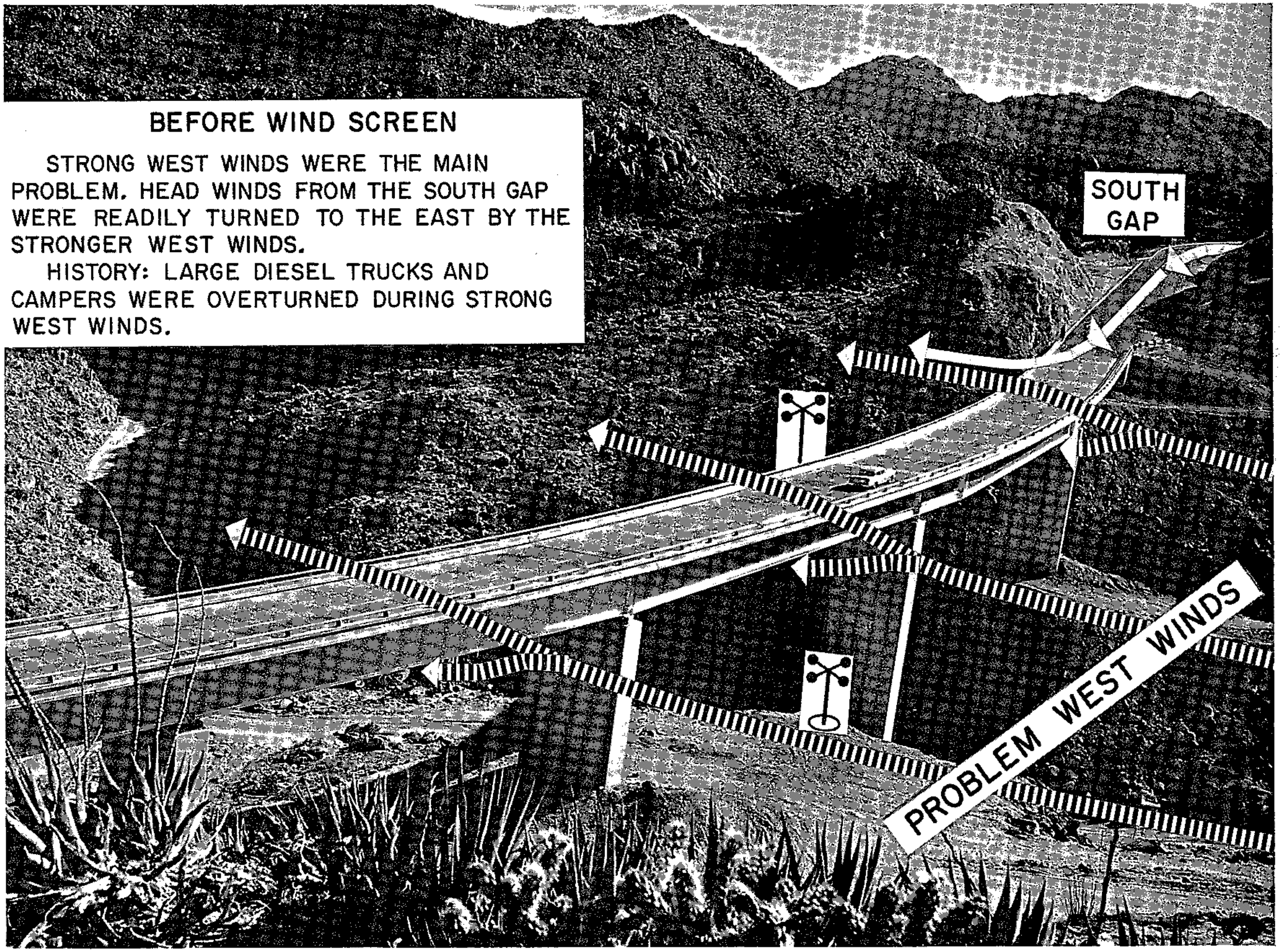


FIGURE 13 CONDITIONS BEFORE WIND SCREEN

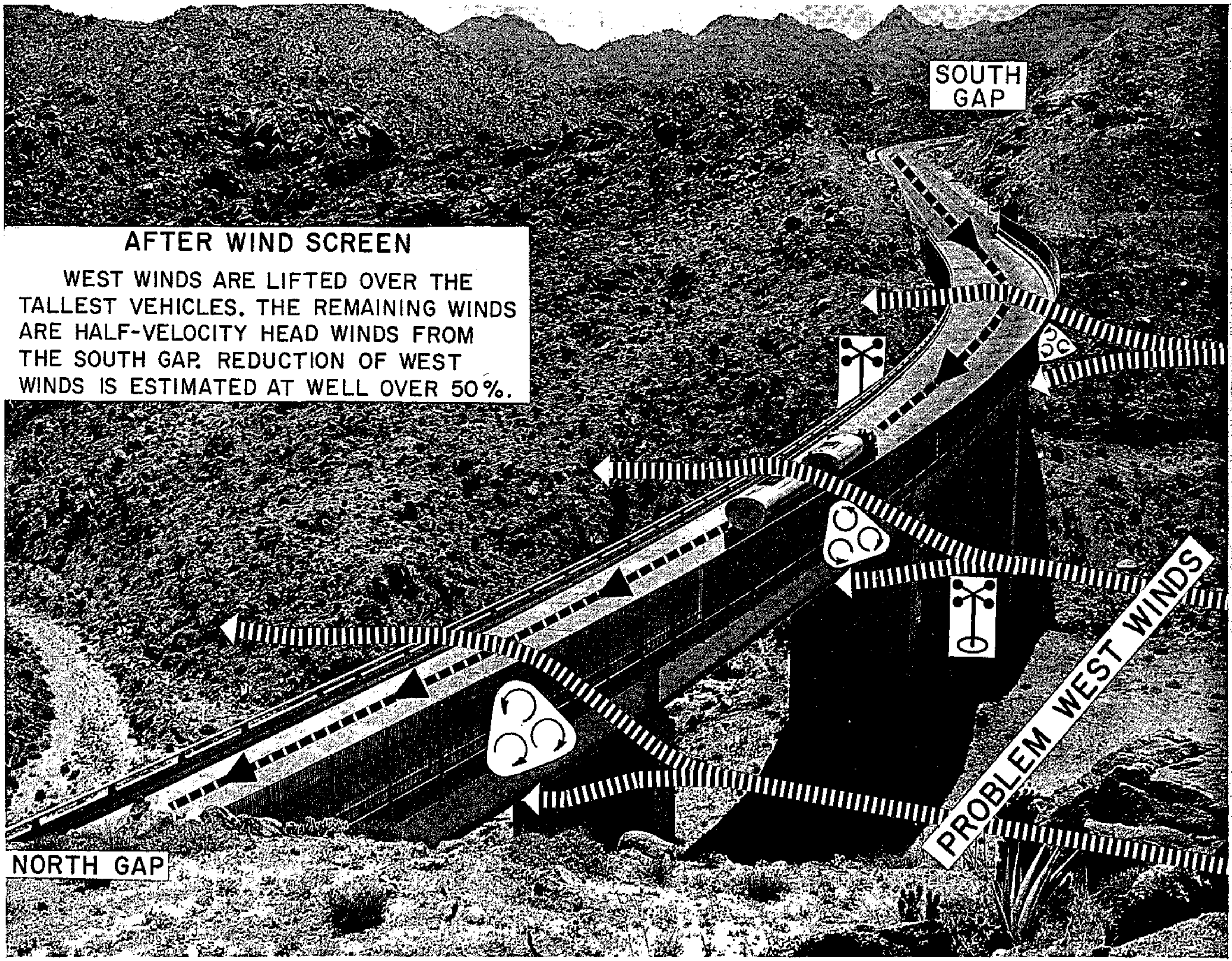


FIGURE 14 CONDITIONS AFTER WIND SCREEN

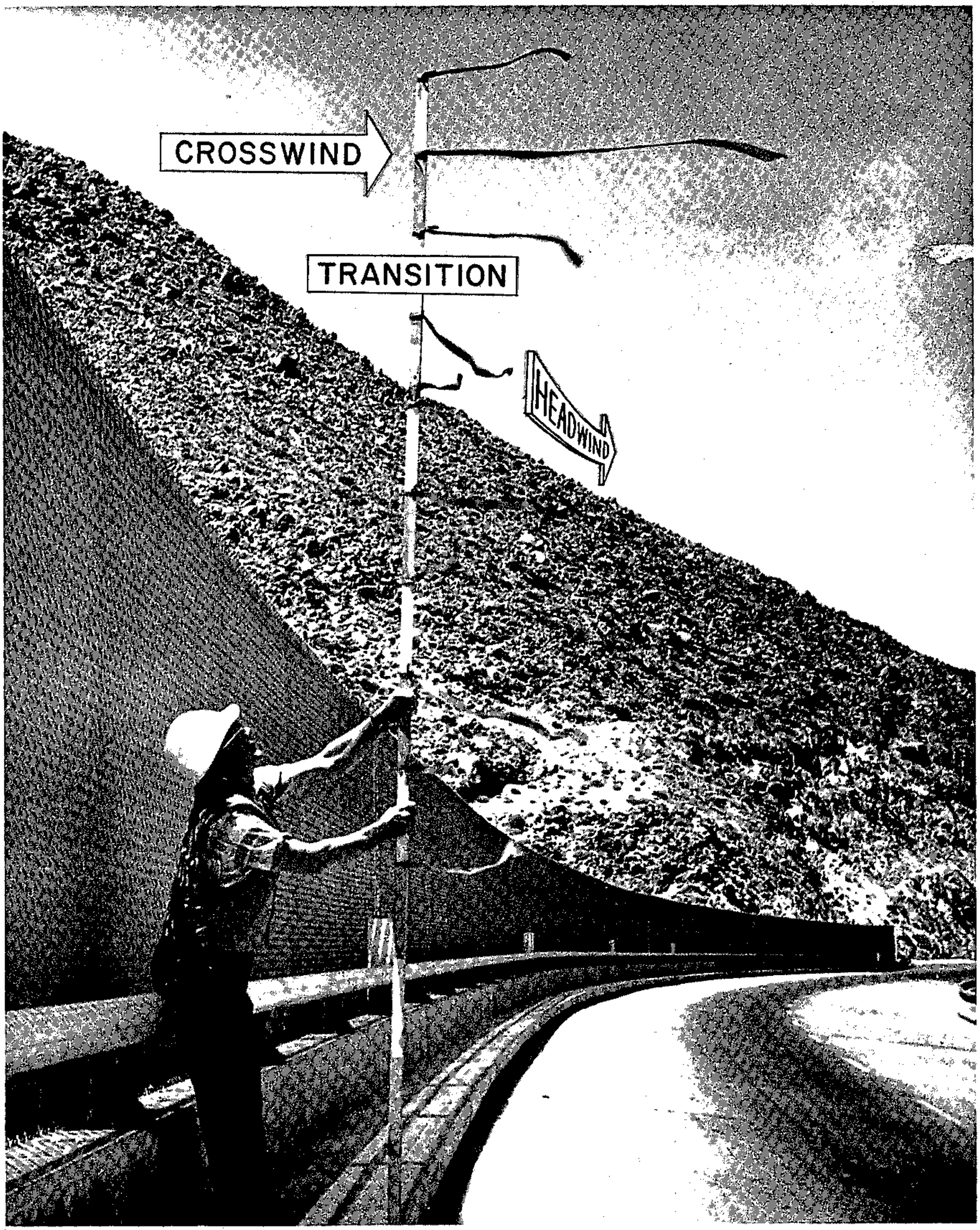


FIGURE 15 STRONG CROSSWINDS ARE DEFLECTED OVERHEAD
LESSER HEADWINDS REMAIN ON BRIDGE

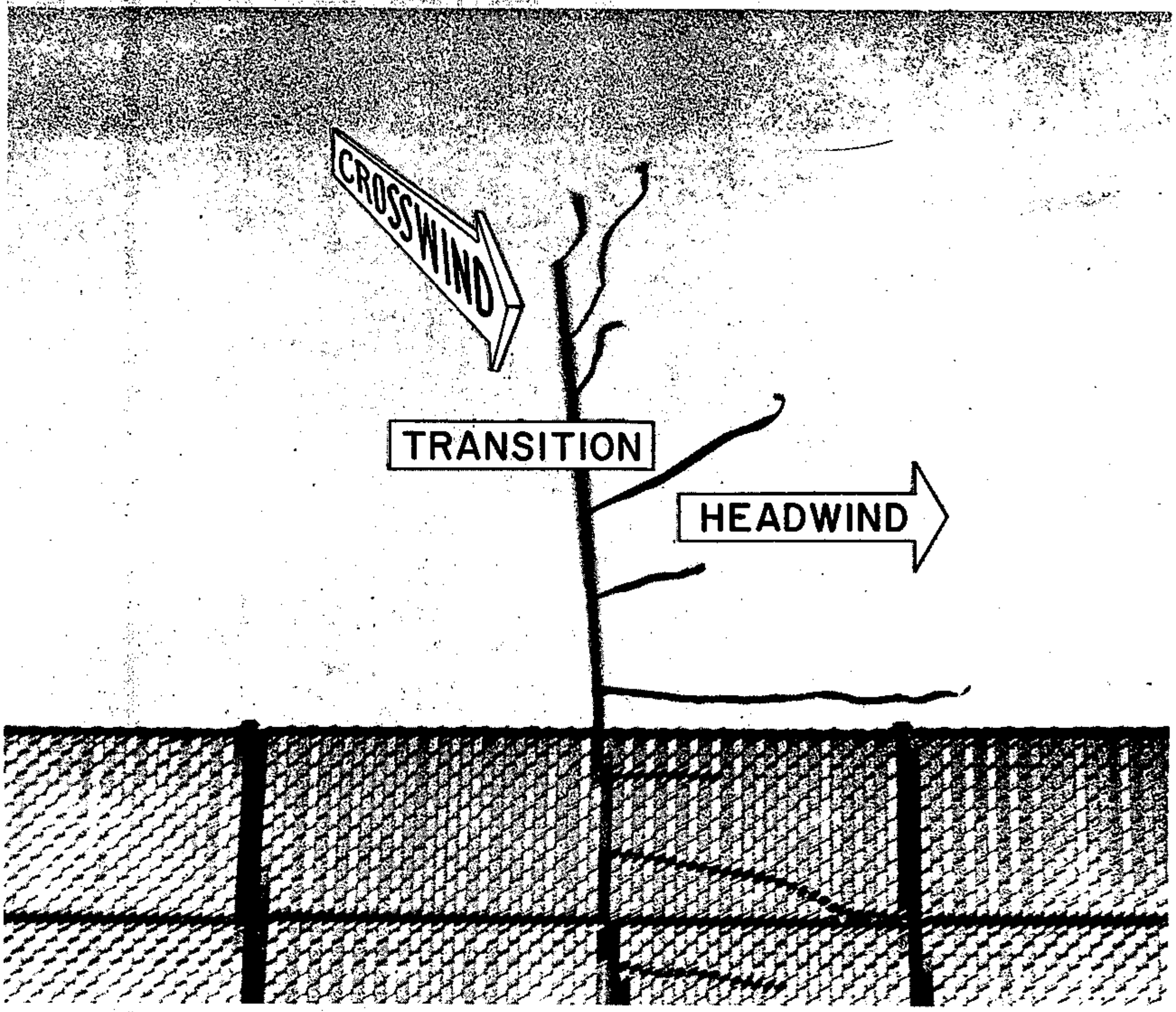


FIGURE 16 SAME AS FIGURE 15, FACING THE SLATTED SCREEN

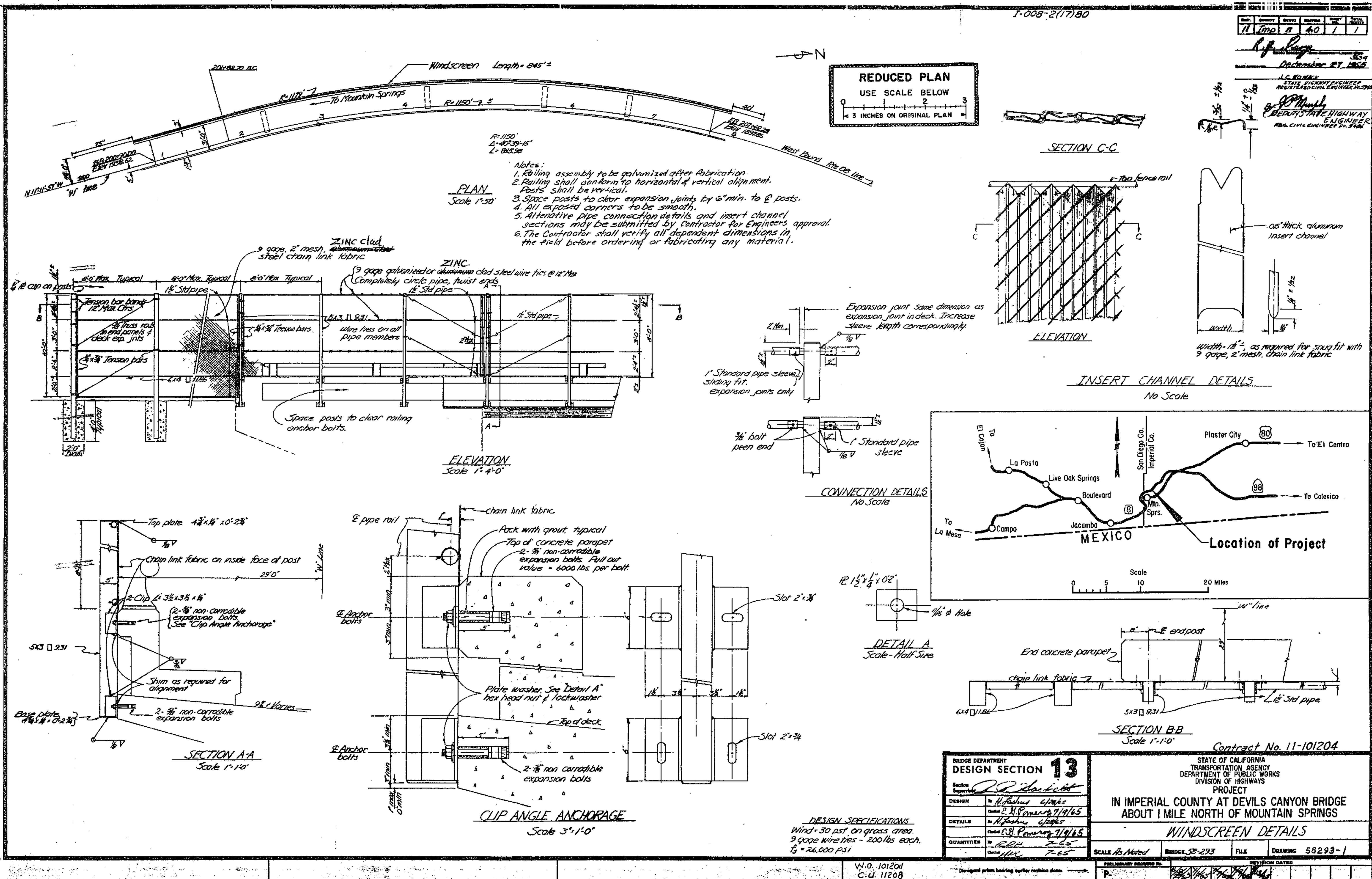

I-008-2(17)80
REDUCED PLAN
USE SCALE BELOW
0 1 2 3
3 INCHES ON ORIGINAL PLAN
Windscreen Length = 845'±
To Mountain Springs
West Bound Rte 08 line
'W' line
PLAN
Scale 1"=50'
R=1150'
Δ=40°39'-15"
L=815.98
Notes:
1. Railing assembly to be galvanized after fabrication.
2. Railing shall conform to horizontal & vertical alignment. Posts shall be vertical.
3. Space posts to clear expansion joints by 6" min. to ℄ posts.
4. All exposed corners to be smooth.
5. Alternative pipe connection details and insert channel sections may be submitted by Contractor for Engineers approval.
6. The Contractor shall verify all dependent dimensions in the field before ordering or fabricating any material.
9 gage, 2" mesh, ZINC clad steel chain link fabric
ZINC
9 gage galvanized or ZINC clad steel wire ties @ 12" Max
Completely circle pipe, twist ends
1½" Std pipe
8'-0" Max Typical
Tension bar bands 12" Max Ctrs.
Tension bars
Wire ties on all pipe members
Space posts to clear railing anchor bolts.
ELEVATION
Scale 1"=4'-0"
SECTION C-C
Top fence rail
ELEVATION
.05" thick aluminum insert channel
Width = 1⅝"±, as required for snug fit with 9 gage, 2" mesh, chain link fabric
INSERT CHANNEL DETAILS
No Scale
Expansion joint same dimension as expansion joint in deck. Increase sleeve length correspondingly.
1" Standard pipe sleeve, sliding fit, expansion joints only
⅜" bolt peen end
1" Standard pipe sleeve
CONNECTION DETAILS
No Scale
Plaster City
To El Centro
To Calexico
El Cajon
La Posta
Live Oak Springs
Boulevard
Jacumba
Campo
La Mesa
San Diego Co.
Imperial Co.
Mtn. Sprs.
MEXICO
Location of Project
Scale
0 5 10 20 Miles
Top plate
Chain link fabric on inside face of post
2-Clip
5x3 ▯ 9.31
Shim as required for alignment
Base plate
2-⅝" non-corrodible expansion bolts
SECTION A-A
Scale 1"=1'-0"
℄ pipe rail
chain link fabric
Pack with grout, typical
Top of concrete parapet
2-⅝" non-corrodible expansion bolts. Pull out value = 6000 lbs per bolt.
℄ Anchor bolts
Plate washer, See Detail A, hex head nut & lockwasher
Top of deck
2-⅝" non corrodible expansion bolts
Slot 2"x¾
CLIP ANGLE ANCHORAGE
Scale 3"=1'-0"
¹¹⁄₁₆" ⌀ Hole
DETAIL A
Scale - Half Size
End concrete parapet
℄ endpost
chain link fabric
1½" Std pipe
SECTION B-B
Scale 1"=1'-0"
DESIGN SPECIFICATIONS
Wind - 30 psf on gross area.
9 gage wire ties - 200 lbs each.
fs = 26,000 psi
Contract No. 11-101204
BRIDGE DEPARTMENT
DESIGN SECTION 13
STATE OF CALIFORNIA
TRANSPORTATION AGENCY
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
PROJECT
IN IMPERIAL COUNTY AT DEVILS CANYON BRIDGE
ABOUT 1 MILE NORTH OF MOUNTAIN SPRINGS
WINDSCREEN DETAILS
SCALE As Noted
BRIDGE 58-293
DRAWING 58293-1
W.O. 101201
C.U. 11208
11 Imp 8 4.0 1 1
DEPUTY STATE HIGHWAY ENGINEER

FIGURE 8