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# Corrugated Steel Plate Structures with Continuous Longitudinal Stiffeners: Live Load Research and Recommended Design Features for Short-Span Bridges

A. E. BACHER AND D. E. KIRKLAND

**The deformation of longitudinally stiffened long-span corrugated steel culverts (beneath shallow overfills) due to live load, backfill, and overfill conditions is investigated. A culvert's structural configuration was monitored from installation through the introduction of live loads. The results of this research at Stenner Creek, and the P–13 proof test loading at Weir Canyon, have led to the conclusions that are recommended herein for incorporation in the design phase. Long-span corrugated metal structures that successfully incorporate these recommended design features are noted.**

In 1963 the California Department of Transportation (Caltrans), in cooperation with the Federal Highway Administration, initiated a $3.5 million culvert research program to assess structural behavior of culverts embedded in deep embankments. Included in this extensive culvert research program were three structural steel plate pipes: Chadd Creek, Apple Canyon, and DB Culvert, previously reported *(1–6)*.

Caltrans has also completed a Category 2 (construction evaluated) research project of a super span design at Stenner Creek. Most recently, a proof test for P–13 loading was performed on a multiple super span at Weir Canyon.

Special features for long-span corrugated steel plate structures (with continuous longitudinal stiffeners) have been implemented on subsequent Caltrans projects as a consequence of the Category 2 Caltrans culvert research project at Stenner Creek. Four permanent super spans and one permanent maxi span as well as two temporary super span corrugated steel plate bridges have been successfully installed in California. In addition, Caltrans has reviewed approximately 30 super span city and county installations.

California Department of Highways, 1120 N Street, Sacramento, Calif. 95814.

## STENNER CREEK RESEARCH

Caltrans completed a Category 2 culvert research project at Stenner Creek, Bridge 49–146, in 1978, which included significant live load research findings (Figures 1 and 2). Live load design has been, and continues to be, a design consideration for minimum overfills on underground steel structures. The objective at Stenner Creek was to monitor (Figures 3 and 4) the shape changes due to backfilling and to live load in combination with incremental increases in overfill. It is apparent that live load can be a factor on a long-span culvert under shallow fill. The culvert is subject to flexing movement as the load passes over it.

### Peripheral Shape Changes

Each of the six transverse sections (Figure 5) had a designated point on either side and a point on top that corresponded to points

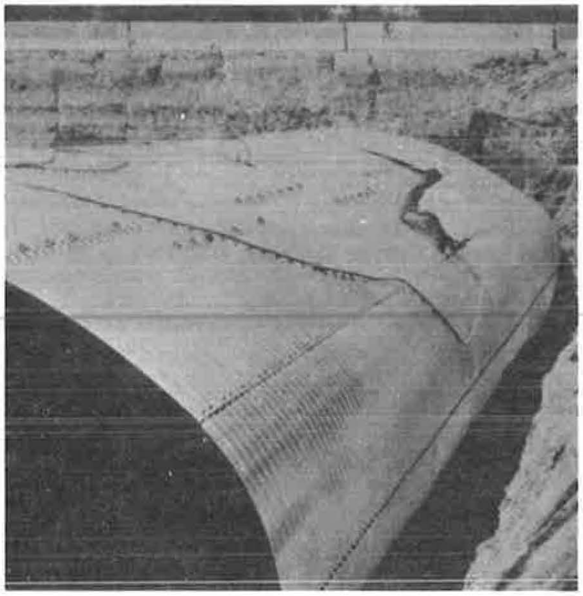


**FIGURE 1 Stenner Creek—structural plate assembly.**

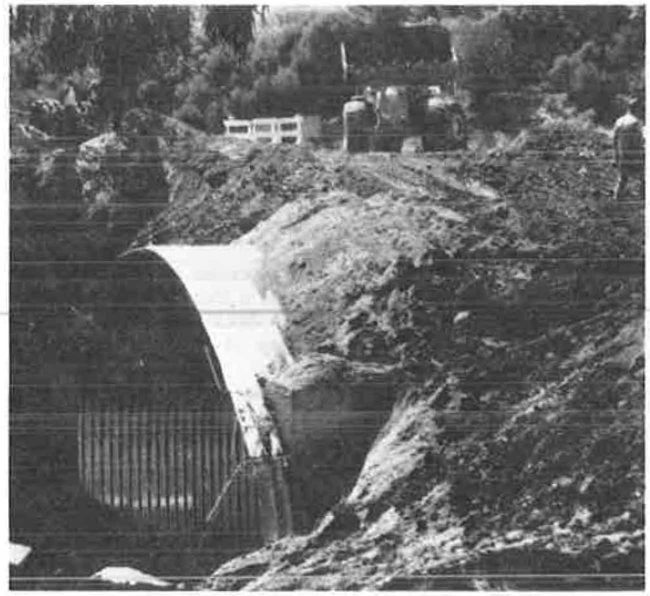


**FIGURE 3 Stenner Creek—backfilling.**

on the existing invert slab to facilitate the measurement of the span and rise.

Measurement was accomplished by using a 50-ft tape between the horizontal points. Vertical dimensions were measured using an extended rod. Measurements were taken to the nearest 1/8 in.

Five points between the thrust beams were carefully located and hooks were welded to the structural plate. At these points the Caltrans Transportation Laboratory used deflection gauges to automatically record the peripheral shape changes as the (Figures 6 and 7) wheel load moved across the culvert. Tape switches (Figures 8 and 9) were placed across the wheel load path for the center and outer deflection gauges to reference the truck with respect to these gauges.

### Soil Load Geometry

Horizontal and vertical dimensions were measured after the assembly of the structural plates, again after the thrust beam was placed and backfilled, and finally after backfilling to grade (Figure 10).

The variations in both vertical and horizontal dimensions were found to be within specified limits and will provide guidelines for future long-span culvert installations. The maximum variation in both the horizontal and the vertical dimensions during backfilling was 6 in. for all observed locations.

Between initial assembly of all the plates and backfilling behind the thrust beam, the rise increased approximately 5 in. accompanied by a corresponding 6-in. decrease in span width. Subse-

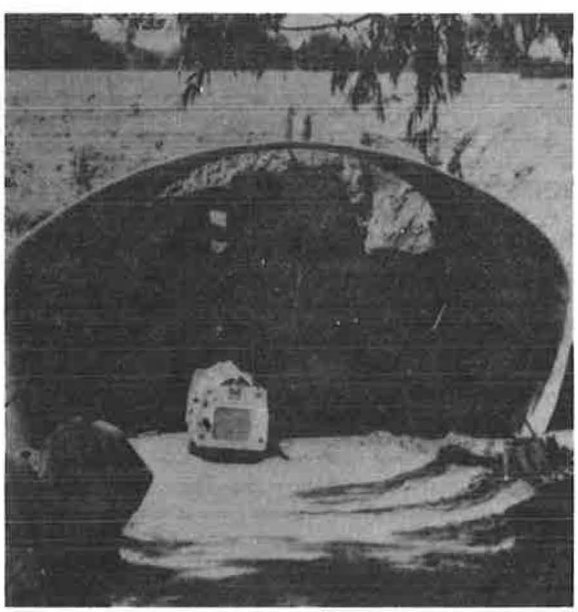


**FIGURE 2 Stenner Creek—scaffolding for deflection gauges.**

**FIGURE 4 Stenner Creek—compacting structure backfill.**

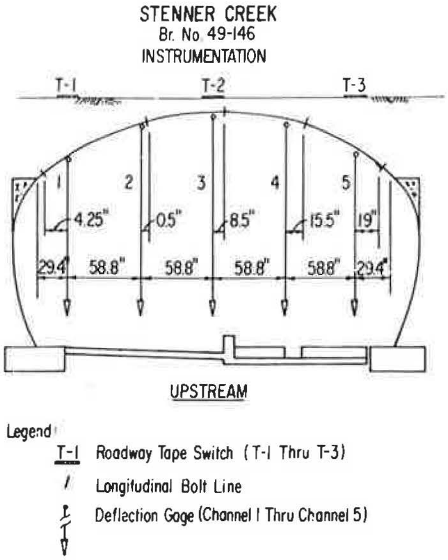



**FIGURE 5 Stenner Creek—instrumentation.**

quent to backfilling behind the thrust beam, there was an additional 1-in. increase in the rise, and the span had variations of ½ in. or less. The design span and rise dimensions were 35 ft 4 in. and 20 ft 0 in. The completed structure span and rise dimensions ranged between 35 ft 2 in. and 35 ft 4 in. for the span and 19 ft 11 in. and 20 ft 1 in. for the rise.

### Live Load

An H20 loading (Figure 11, run 5) of 32 kips with 1 ft of overfill resulted in a maximum deflection of 0.40 in. Although the magnitude of the deflection was only ½ in., the more significant factor was the apparent reversal of stress because of the ripple effect as

**FIGURE 7 Stenner Creek—measuring wheel load.**

the load passed over the long-span culvert. Subsequent incremental fill height increases of 1 ft reduced the corresponding live load deflection to approximately 50 percent of those that occurred at the preceding lower fill heights (i.e., 0.20 in. for 2 ft, 0.10 in. for 3 ft, and 0.05 in. for 4 ft). Because only 0.05-in. or 1/16-in. deflection occurred with 4 ft of overfill, the minimum overfill height of span length/8, which corresponds to 4.5 ft of overfill, is considered by Caltrans to be a reasonable minimum. The 6-ft minimum cover at Stenner Creek, therefore, provides assurance that, on a long-term basis, the live load will not adversely affect the long-span culvert design.

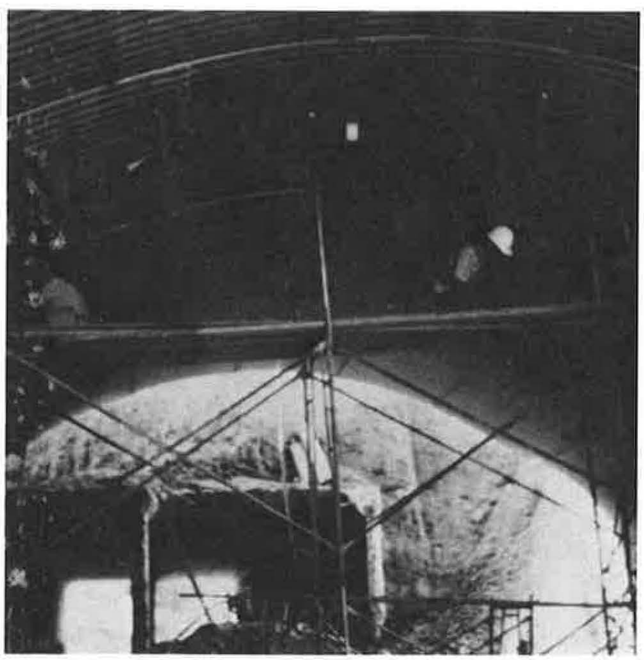


**FIGURE 6 Stenner Creek—placing deflection gauges.**

**FIGURE 8 Stenner Creek—placing tape switches.**

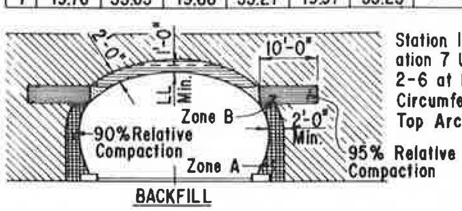
FIGURE 9 Stenner Creek—Transportation Laboratory vehicle.

The actual plot of the change in the peripheral configuration of the upper structural plate was of extreme significance. At the 1-ft overfill, a moment was induced in the structural plate. The plate was deflected upward in a ripple effect. It was not a case of pure downward deflection. Consequently, live load moment is a definite design consideration when design overfills are as shallow as 1 or 2 ft. It should be further noted that at the 4-ft overfill (Figure 12, run 15), the structural plate peripheral shape exhibited minimum deflection only. This indicates that with these overfills there is compatibility between the observed loading conditions and the design assumption that moment is not a design consideration, and ring compression becomes the primary design concern for the structural plates.

For live load (Figures 13 and 14), based on the research at Stenner Creek where the minimum overfill is less than span length/8, a 2-ft layer of three-sack concrete is placed between the thrust beams or steel wings.

STENNER CREEK
Br. No. 49-146
DISPLACEMENTS

| Sta | No Backfill | | Zone A Complete | | Zone B Complete | | L.L.Test 1' Overfill | | Backfill Complete |
|---|---|---|---|---|---|---|---|---|---|
| | Rise | Span | Rise | Span | Rise | Span | Rise | Span | |
| 1 | 19.74 | 35.83 | — | 35.32 | 20.07 | 35.27 | — | 35.28 | — |
| 2 | 19.60 | 35.67 | 20.02 | 35.19 | 20.09 | 35.18 | 20.11 | 35.18 | 20.11 |
| 3 | 19.62 | 35.70 | 20.02 | 35.23 | 20.09 | 35.22 | 20.11 | 35.23 | 20.09 |
| 4 | 19.60 | 35.65 | 19.94 | 35.18 | 19.99 | 35.18 | 20.00 | 35.22 | 19.96 |
| 5 | 19.64 | 35.78 | 19.98 | 35.36 | 20.03 | 35.24 | 20.05 | 35.37 | 20.00 |
| 6 | 19.66 | 35.68 | 19.95 | 35.28 | 20.00 | 35.28 | — | 35.32 | — |
| 7 | 19.76 | 35.63 | 19.88 | 35.27 | 19.97 | 35.25 | — | 35.28 | — |




Station 1, Downstream end; Station 7 Upstream end; Station 2-6 at Each Intevening Circumferentral Seam of the Top Arch.

FIGURE 10 Stenner Creek—displacements.

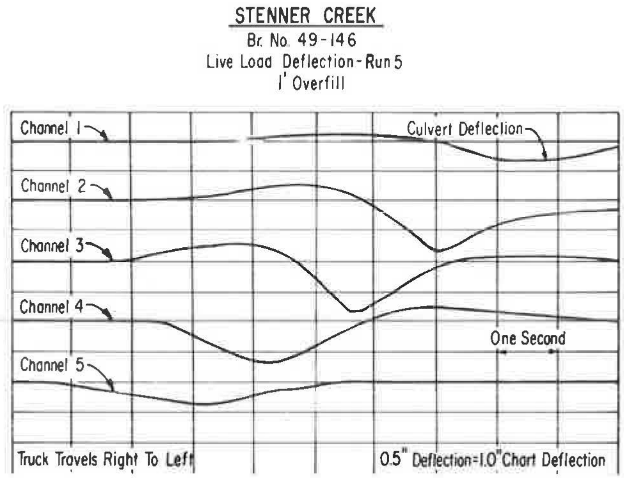



FIGURE 11 Stenner Creek—live load deflection, 1 ft of overfill.

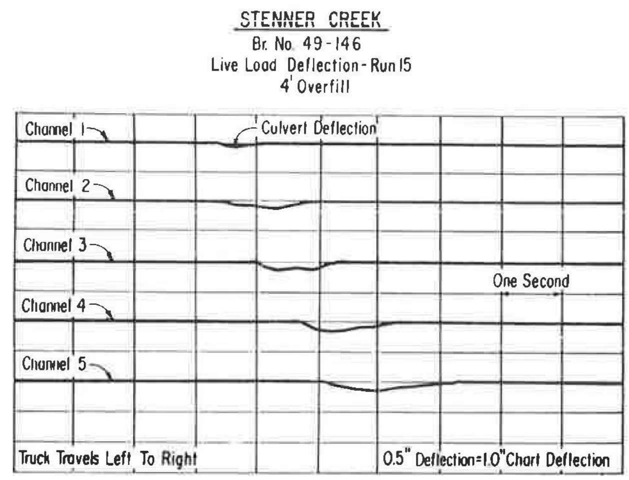



FIGURE 12 Stenner Creek—live load deflection, 4 ft of overfill.

FIGURE 13 Stenner Creek—test vehicle.

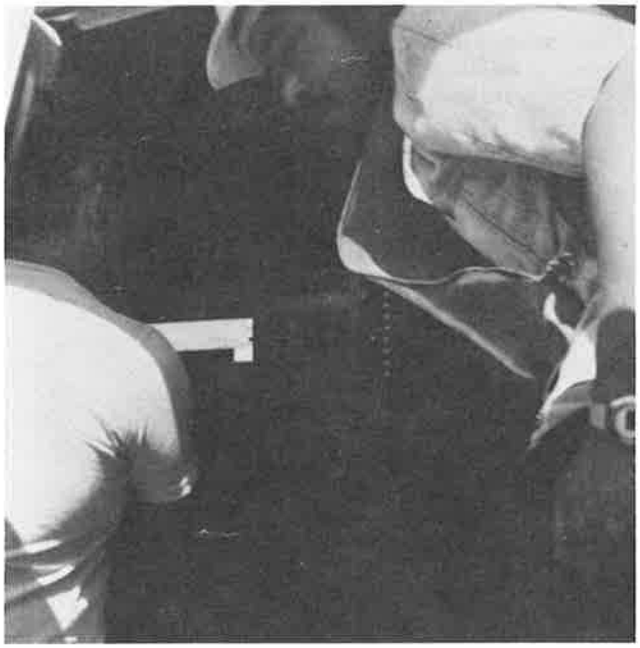


**FIGURE 14 Stenner Creek—monitoring deflection plots.**

## ORANGE COUNTY RESEARCH

A super span in Orange County (Figures 15–17) was proof tested using P–13 loading on a double 38 ft 3 in. × 18 ft ellipse at Weir Canyon on July 4, 1984. The structure is a special design outside the standard AASHTO acceptable limits for minimum cover and top radius. Minimum cover is only 1.7 ft and top arc radius is 29 ft, whereas AASHTO standards limit radius to 25 ft with 4 ft of cover. There was no observable movement evident on any monitoring run. This result confirms the effectiveness of the Caltrans method of using concrete over the top when cover height is below minimum.

### Implementation

Since the Stenner Creek research was completed, Caltrans has successfully installed six additional long-span corrugated steel structures. Of the seven total installations, five are permanent and two are temporary (Figure 18)—in use only during the duration of the stage construction. Incidentally, there has been concern for their structural integrity because failures of long-span structures have occurred, as reported in FHWA–RD–77–131, August 1977.

Caltrans has developed special features to ensure the safety and integrity of these cost-effective alternatives to bridges in the 20- to 40-ft span range.

**FIGURE 15 Weir Canyon—completed multiple super span.**

**FIGURE 16 Weir Canyon—monitoring deflection.**

### Recommended Special Features

The special features that assure safety and structural integrity include (Figure 19) *(a)* providing concrete headwalls or slope

**FIGURE 17 Weir Canyon—P–13 loading.**

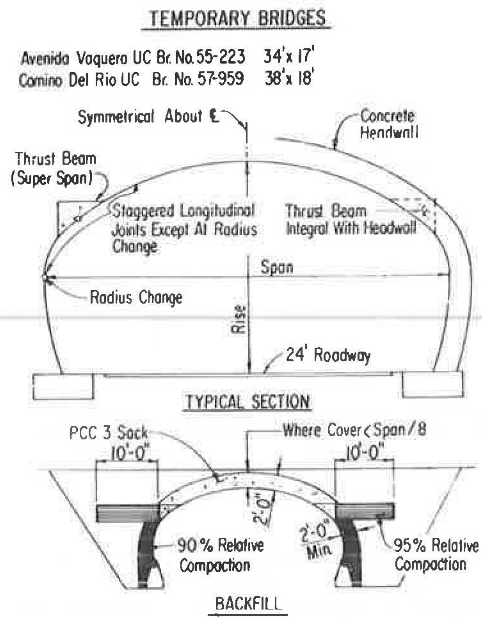



**FIGURE 18 Temporary bridges—super span.**

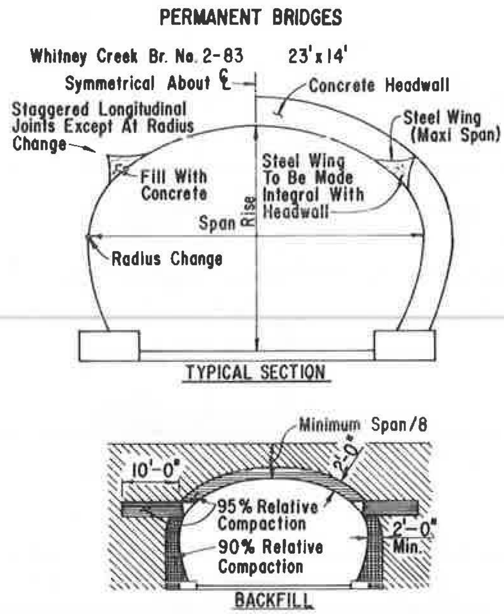



**FIGURE 20 Permanent bridge—maxi span.**

collars; *(b)* requiring the longitudinal joints to be staggered except at the point of radius change; *(c)* specifying a crown angle of 80 degrees; *(d)* specifying a maximum radius of the crown arch of 25 ft; *(e)* providing for a minimum 2-ft thickness of structural backfill at 90 and 95 percent compaction around the periphery (Caltrans specification); *(f)* limiting the skew to 20 degrees; *(g)* for live load, where the cover is less than span length/8, a 2-ft layer of concrete (three sack) shall be placed between the super span thrust beams or maxi span steel wings; and *(h)* extending the thrust beam on super spans into the headwall or slope collar at each end of the structure, and filling the steel wings of maxi spans (Figure 20) with concrete, and providing for an integral connection into the headwalls or slope collars.

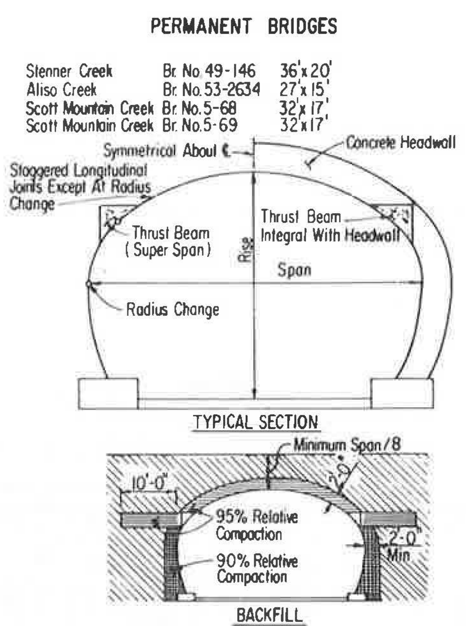



**FIGURE 19 Permanent bridges—super span.**

## Design

The requirement to make the thrust beam or steel wings integral with the headwall provides a composite type of structure with the corrugated steel plate receiving an additional structural restraint by its attachment to the continuous thrust beams or the concrete-filled steel wings. Span-to-rise ratios less than 0.18 may require special design including moment calculations.

Application of ring compression design will provide adequate assurance of the structural competence of either the super span or the maxi span, provided the special features detailed are provided for these structures.

## DIMENSION RATIO

Another interesting observation by Caltrans designers (Figure 21) has been the relationship of dimension ratio and structural steel plate pipe performance and design. Dimension ratio is defined as the inside diameter in inches divided by the depth of corrugation profile in inches. Based on Caltrans' experience, standard plans for Caltrans structural steel plate designs require internal strutting where the dimension ratio varies between 100 and 150. As a consequence of Caltrans' structural steel plate research, special pipe designs, and successful usage of long span designs, it appears that dimension ratios exceeding 150 require that special features (i.e., longitudinal stiffeners) be incorporated into the design of long-span structures.

## SUMMARY

In conclusion, to date, the state of California has realized a total savings of approximately $1 million on the five permanent and two temporary structural steel plate long-span structures with the continuous longitudinal stiffeners. This type of structure can be an economical, structurally viable short-span bridge alternative.

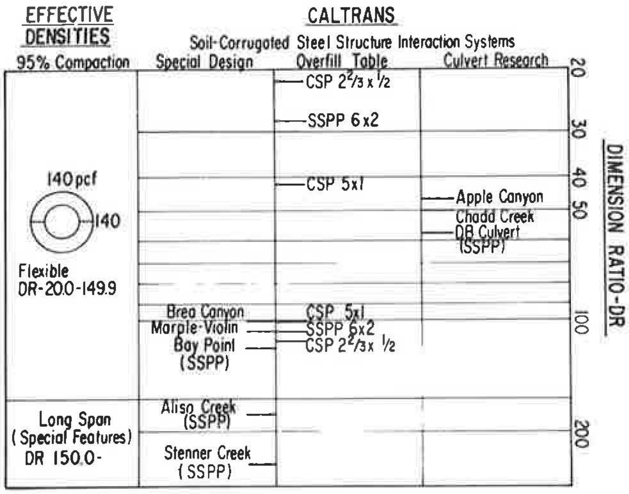



**FIGURE 21 Corrugated steel pipe and structural steel plate pipe—dimension ratio.**

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