U.S. Department of Transportation
Federal Highway Administration

Technical Advisory

Subject

CORRUGATED STEEL GUARDRAIL TERMINALS

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CANCELED

1. PURPOSE. To consolidate information on end treatments that are currently considered acceptable for use with w-beam and thrie-beam guardrails and to provide guidance on appropriate uses for each of them.

2. BACKGROUND

a. High-speed crashes into guardrail terminals are usually more severe than those in which the face of the barrier is struck by errant motorists. Therefore, designers must be aware of the operational characteristics of the numerous terminals available and select a terminal that is most appropriate for a given location. An ideal terminal will not spear, vault, or roll a vehicle in an end-on hit, may allow controlled penetration in some cases, and will provide smooth redirection when struck on the side within its design length of need. Occupant deceleration levels must remain below specified limits in all cases. The specific tests and evaluation criteria currently used to develop guardrail terminals are found in the NCHRP Report 230, "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances." It should be noted that work is nearing completion on NCHRP Report 350, "Recommended Procedures for the Safety Performance Evaluation of Highway Features," a document which will replace NCHRP Report 230 and which will likely provide guidance for testing and evaluating terminals in the future.

b. General information on guardrail terminals is contained in Chapter 5 of the 1989 AASHTO "Roadside Design Guide." More specific information on the Breakaway Cable Terminal (BCT) and the Eccentric Loader Terminal (ELT) has been previously issued in FHWA Technical Advisories T 5040.23, Corrugated Sheet Steel (W-Beam) Guardrail, dated March 13, 1984; T 5040.25, W-Beam Guardrail End Treatments, dated January 7, 1986; and T 5040.25, Chg 1, W-Beam Guardrail End Treatments, dated December 15, 1987. Additionally, a FHWA memorandum sent to all Regional Administrators on March 27, 1991, provided information on the Modified Eccentric Loader Terminal (MELT). Information on proprietary terminals has been distributed to the field via copies of FHWA acceptance letters to various manufacturers. Except as noted below, information contained in this Technical Advisory supplements the earlier documents.

3. <u>SUMMARY</u>

a. Terminals for w-beam and thrie-beam guardrails are an essential part of every barrier installation, providing an anchor against which the full tensile strength of the rail can be developed for downstream hits while remaining crashworthy for end-on impacts.

b. In the past, only a few terminal types were available for selection by a designer. Today, several non-proprietary terminals, mostly of a breakaway type, and several proprietary products are available for use.

c. Paragraph 4 contains information on the evolution and current status of all terminals considered suitable for use with corrugated sheet steel guardrails (w-beam and thrie-beam).

4. <u>RELATED TECHNICAL INFORMATION</u>

a. <u>General</u> - guardrail terminals can be categorized as non-proprietary or proprietary as defined in paragraphs 4b and 4c, and must demonstrate crashworthy performance through full-scale testing before they can be used in the field. These tests are typically run on level terrain and on installations having an obstruction-free runout area behind and beyond the terminal. The runout area is, of course, essential for terminals which fracture and permit penetration behind the barrier (gating terminals). Unless these conditions are reasonably approximated in the field, actual terminal performance may be degraded. For the terminals listed below, optimal performance can be expected only when the grading is such that an errant vehicle can strike the terminal with all wheels on the ground and with little or no pre-crash roll angle.

Normally, this will require that the flat slope between the barrier and the roadway be continued at least 1.5 m (5 feet) behind the terminal to accommodate off-center impacts. For gating terminals, a relatively clear runout path is also needed. The actual distance required will vary depending on the size and speed of the vehicle and on its impact angle. An obstacle-free rectangular area extending a minimum of 22.5 m (75 feet) beyond the terminal (parallel to the rail) and 6.1 m (20 feet) behind the rail is suggested. However, a runout area of that size will not necessarily accommodate all impacts that might occur.

b. Non-Proprietary Terminals - terminals in this category are generally unpatented or can be provided without payment of royalties to a manufacturer or to an individual. Included in this list are turned-down terminals, breakaway cable terminals, and w-beam guardrail anchored in a cut slope. A discussion of each follows:

(1) Turned-Down Terminal

(a) The turned-down w-beam terminal was developed to eliminate spearing of the rail into the passenger compartment of impacting vehicles and was a significant improvement over earlier full-height, stand-up ends. However, both field experience and subsequent full-scale crash testing showed that vehicle rollover is likely with these terminals under high speed impact conditions. The initial tests on the turned-down terminal were run on a rigid design (i.e., the rail was firmly mounted to the first full-height post with a second, shorter post sometimes installed between the anchor and the first post, creating an unyielding ramp for end-on or near end-on hits). Modified versions of this anchor, which eliminated all intermediate posts and weakened the attachment to the first full-height post and several adjacent ones, were developed in an attempt to overcome the rollover problem. Two primary schemes were used to weaken the connection: use of smaller diameter post bolts in the first several posts, or a design in which the w-beam railing was nested against w-beam back up plates bolted to the first few posts and held in place with malleable steel-strap clips over the rail and back up plates.

(b) Although these modifications are considered an improvement over the earlier rigid design, full scale testing revealed two major shortcomings. First, the weakened terminals absorbed very little energy, allowing the impacting vehicle to travel significant distances beyond or on top of the guardrail. Second, although rollover was avoided in testing 1022-kg (2250-pound) cars on level, firm terrain, the roll angle of several vehicles was relatively high, making rollover far more likely in high speed impacts in the field where the area beyond a guardrail is oftentimes steeply sloped and irregular. None of the modified designs passed the 818-kg (1800-pound) vehicle tests.

(c) Even the Controlled Releasing Terminal (CRT), a turned-down design that is still considered acceptable for use, performed only marginally with an 818-kg (1800-pound) car. When this test vehicle was offset 381 mm (15 inches) toward the road in a 97 kp/h (60 mph) end-on crash, it overturned on the roadway; when offset the same distance away from the road, it travelled on top of the rail approximately 38 m (125 feet) before stopping and incurred significant underbody damage as it slid over the steel posts.

(d) Thus, the primary negative characteristics of turned-down terminals remain their potential for causing rollovers, and for trapping impacting vehicles on top of the rail and leading them into shielded hazards or launching them into hazards located beyond and in back of the terminal. The potential for the second occurrence may be reduced somewhat by flaring the terminal away from the roadway.

(e) Based on observed crash test performance and reported field experience, the FHWA has prohibited the use of turned-down w-beam terminals within the designated clear zone on high-speed, high-volume roads and has defined such roads as any with operating speeds of 80 kp/h (50 mph) and above and with traffic volumes in excess of 6,000 vehicles per day.

The ADT value should be considered a general guideline and may be adjusted as appropriate for local conditions, but the continued use of turned-downs under any high speed condition is discouraged. Turned-down terminals remain appropriate for use on trailing ends of traffic barriers on divided highways and in other locations where end-on, high speed accidents are unlikely. On low speed facilities where the severity of most impacts is expected to be low, they may be used at the discretion of the responsible highway agency.

(f) The FHWA prohibition on turned-down terminals has not been extended to use with weak-post w-beam systems, not because of demonstrated crashworthiness, but rather because alternatives to the turned-down end have not been crash-tested for use with weak-post w-beam systems.

(2) <u>Breakaway Cable Terminal</u>

(a) The Breakaway Cable Terminal (BCT) was developed to eliminate the vaulting/rollover problem inherent with a turned-down anchor. The BCT is a full-height, flared w-beam terminal with an integral cable anchorage. The two end posts are designed to fracture when struck head-on, allowing a vehicle safe penetration behind the barrier. For downstream hits, tension in the rail element is transferred to the base of the end post via the cable and an impacting vehicle is redirected. When originally tested with 2045 kg (4500-pound) vehicles at 97 km/h (60 mph) and 1022-kg (2250-pound) vehicles at 65 km/h (40 mph), the BCT functioned adequately. When it was later tested under the NCHRP Report 230 with an 818-kg (1800-pound) vehicle at 97 km/h (60 mph), it proved too stiff in end-on impacts. Another concern was unsatisfactory performance with BCT's that were not installed with the specified 1219-mm (4-foot) parabolic flare. Several instances of passenger compartment intrusion by the w-beam rail have been reported, many of which occurred on improperly flared installations and/or as a result of side-on impacts into the terminal end. A third concern with BCT performance is related to site conditions. Since the BCT is designed to allow controlled penetration, the area immediately beyond the terminal should be traversable to minimize the likelihood of vehicle rollover and to eliminate subsequent fixed object impacts.

(b) Thus, to attain the best performance possible, the BCT must be installed with the correct 1219-mm (4-foot) parabolic flare, the area in advance of and immediately beyond the terminal must be essentially flat, and a reasonably clear, traversable run-out area must be provided. However, even under these conditions the BCT may be too stiff for small cars and can still penetrate impacting vehicles if struck directly in line with the first section of the w-beam. The use of diaphragms in the end section (specified in the original BCT design and still used by some highway agencies) may reduce the likelihood of spearing.

(c) Several State highway agencies use the BCT in conjunction with strong steel post w-beam systems. While most use, nominal, 203-mm by 152-mm (8-inch by 6-inch) timbers for the two breakaway posts, some use the steel tube slip-base post design from NCHRP Research Results Digest 84. In one crash test with an 818-kg (1800-pound) car the second post did not release properly and the w-beam rail hinged at the post and penetrated the passenger compartment. In another test, an 818-kg (1800-pound) car impacting at only 64 km/h (40 mph) was stopped in 1372 mm (4.5 feet) and experienced unacceptably high decelerations. In general, wooden breakaway posts set in steel tubes perform better, have no torque requirement, and are easier to install and repair than either steel slip-base posts or timber posts set in concrete.

(d) It has also become evident through research and development of the Eccentric Loader BCT and the Modified Eccentric Loader Terminal (MELT) that, unless additional posts in the BCT are weakened, deceleration levels of an 818-kg (1800-pound) car following a high-speed, end-on hit are likely to exceed NCHRP 230 maximum values whether the non-breakaway posts are timber or steel.

(e) Because of the large number of BCT's that have been installed and current awareness of their limitations, several research efforts have been directed at modifications to existing BCT's. Weakening posts 3, 4, and 5 by drilling holes through the 152-mm (6-inch) dimension resulted in acceptable decelerations in two full-scale tests of the wood post system, but the kinked w-beam rail element penetrated or significantly deformed the passenger compartment in both cases. If additional testing is done, the results will be distributed as they become available. In the meantime, State highway agencies must remain aware of the hazard created by improper BCT location and/or installation and the possibility that an acceptable installation may not perform satisfactorily if an errant motorist strikes the end in line with the rail element, as sometimes happens when the driver attempts to return to the roadway after a roadside encroachment. Furthermore, current vehicle designs are such that side impacts into the BCT may result in severe passenger compartment intrusion. This is true in general of all full-height stand-up terminals.

(3) <u>Eccentric Loader BCT</u>

(a) As a result of reported field experience and observed crash test results, the Eccentric Loader BCT was developed to improve the performance of the original BCT and specifically to accommodate small car end-on impacts. Four significant changes distinguish the Eccentric Loader from the original BCT: a structural steel nose inside a vertical section of corrugated steel pipe; elimination of all rail-to-post bolts at posts 2 through 6; the use of weakened wood posts at posts 3, 4, 5 and 6; and the addition of a steel strut between posts 1 and 2.

(b) The first of these modifications, the nose piece, has three essential functions:

<u>1</u> For end-on impacts, together with the corrugated steel pipe, it spreads the

resisting load of the w-beam rail element over a larger area of the impacting vehicle and prevents the end of the rail element from spearing the car, although significant occupant compartment deformation is likely in side-on impacts;

2 It ensures that the first post breaks and releases the anchor cable before any longitudinal load can develop in the w-beam rail element;

3 It induces a moment at the end of the w-beam, reducing the force needed to overcome its column strength, thus facilitating desired buckling.

(c) The second change was the elimination of the rail-to-post bolts, which reduces the column strength of the w-beam, allowing it to bow away from the posts and to form hinges outside the car's path in an end-on hit, allowing safe penetration behind the rail.

(d) The third major design change was the weakening of posts 3 through 6. In earlier tests, both with the original BCT and with the Eccentric Loader, vehicle contact with the third and subsequent posts resulted in high decelerations and often induced rollover. To minimize this problem, these standard wood posts were replaced by posts with holes drilled at and below the groundline. Because these holes make the posts weaker, the spacings are reduced from the standard wood post BCT layout. The addition of a blockout on the second post further increases the curvature near the end of the rail, thereby further reducing the w-beam column strength.

(e) The final change from the original BCT is the addition of a steel strut connecting posts 1 and 2 at the groundline. The removal of rail-to-post bolts in the terminal puts more load on the anchor cable in downstream hits, and the strut ties the first two posts together to resist the increased cable load.

(f) Failure to follow the recommended details of the Eccentric Loader BCT may result in unsatisfactory field performance. It is particularly important that the grading around and in front of the terminal be essentially level. A maximum 15:1 cross-slope is recommended; a slope steeper than 10:1 should not be permitted. Like the original BCT, the Eccentric Loader BCT is designed to be penetrated. Therefore, the area behind the rail must be reasonably traversable and obstacle-free. A minimum run-out path of 22.5 m (75 feet) is recommended.

(g) The Eccentric Loader BCT was tested in two configurations: a 1219-mm (4-foot) parabolic flare, and a 457-mm (1.5-foot) flare for use at sites where a full flare could not be attained. However, the latter design performed marginally when hit end-on by both the 818-kg (1800-pound) and 2045-kg (4500-pound) cars, imparting a high roll angle to both vehicles on level terrain.

(4) Modified Eccentric Loader Terminal (MELT). Although the Eccentric Loader successfully passed the NCHRP 230 acceptance tests and is demonstrably softer in end-on hits than the BCT, it has not been widely used. In an attempt to simplify its design and to increase its use in the field, the Eccentric Loader was tested with a standard BCT end section with bolt-in 2.67-mm (0.105-inch or 12-gage) thick base metal, steel diaphragms. Except for the nose section and its attachment to the rail end, the MELT is identical to the Eccentric Loader BCT. Two tests were run on a MELT with a 1219 mm (4-foot) parabolic flare. These were the 818-kg (1800-pound) end-on test and the 2045-kg (4500-pound) length-of-need test. Based on the results of these tests and the earlier Eccentric Loader acceptance test series, the MELT is considered operational. Since the MELT was not tested with a 457-mm (1.5-foot) flare and the Eccentric Loader BCT with that offset was marginal, the MELT should only be used with the standard 1219-mm (4-foot) parabolic flare.

(5) W-Beam Guardrail Anchored in a Backslope. Where a roadway is in a cut section, it is sometimes possible to carry the end of a W-beam guardrail away from the roadway directly into the backslope. Anchoring a guardrail end in a backslope eliminates the spearing potential, provides necessary anchorage for the w-beam rail, and blocks access to the area immediately behind the barrier if appropriate design and installation principles are followed.

(a) One of the important principles to consider is the need to design an anchor that is capable of developing the tensile strength of the w-beam so the rail will remain a ribbon for redirecting impacting vehicles. Thus, the anchor used should be capable of developing at least 222.3 kN (50 kips), which is the approximate strength of the standard BCT cable anchor. In practice, a buried 610-mm (2-foot) wide by 910-mm (3-foot) long by 610-mm (2-foot) deep concrete block has proven adequate. It should be set a minimum of 152 mm (6 inches) into the backslope to lessen the possibility that the terminal will be exposed by erosion and snag an impacting vehicle.

(b) Other important design considerations include selecting an appropriate flare rate, maintaining the full design height of the guardrail above the edge of the travelled way, and providing proper drainage and approach terrain details. The flare rate for strong post w-beam guardrail should not exceed the recommended values in Table 5-5 of the 1989 AASHTO Roadside Design Guide until the guardrail crosses the foreslope/backslope intercept. At that point, it can be flared as sharply as 8:1 to extend it to the backslope. If the roadway has significant superelevation, the flare rate, the height and the location of the barrier may need to be adjusted for optimal performance.

(c) The conceptual design shown on Attachment 3 in FHWA Technical Advisory T 5040.25, dated January 7, 1986, did not perform satisfactorily when tested with a 2045-kg (4500-pound) car at 97 km/h (60 mph) and a 25 degree departure angle from the roadway and is no longer considered acceptable. The decreasing rail height (with respect to the roadway grade) and the 10:1 approach slope allowed the impacting vehicle to strike the top of the rail, which tore, allowing the vehicle to penetrate the barrier and overturn. To achieve satisfactory results, the foreslope in front of the guardrail should be nearly level. However, a second test confirmed that a 10:1 maximum slope can be used provided the height of the barrier remains constant relative to the roadway grade until it crosses the ditch bottom. In this second test, the addition of a w-beam rub rail was necessary because the opening beneath the primary rail exceeded approximately 457 mm (18 inches). This design was successfully tested with a 2045-kg (4500-pound) car at 97 km/h (60 mph) and a 25 degree departure angle. A constant 13:1 flare rate was used in this successful test. This design layout required 41.8 m (137 feet) of w-beam rail in advance of the length of need to reach the anchorage in the backslope. Two addit ional tests were conducted where the only significant change was the use of a steeper flare rate into the backslope. For these tests, a 19-m (62.5-foot) parabolic flare with the end 3.65 m (12 feet) beyond the length of need offset was installed. Both tests failed, confirming the need for a flatter flare rate for high speed, high angle impacts.

(d) A third test was run on an installation with a 19-m (62.5-foot) parabolic flare into the backslope but without a rub rail and at a constant height above the local grade. This resulted in an installation that sloped down gradually as it followed the 10:1 shoulder slope. A 2045-kg (4500-pound) car hitting the rail at 97 km/h (60 mph) and a 15 degree departure angle was redirected. This reduced design may be appropriate where impact conditions are likely to be less than 97 km/h (60 mph) and/or at a departure angle of 15 degrees or less.

(e) A slope transition zone will often be needed between the standard ditch cross-section and the flatter foreslope in front of the guardrail. The resulting approach slope at the back of the ditch (parallel to traffic) should be no steeper than 20:1 relative to the roadway grade. When this approach treatment interferes with drainage, a grated drop inlet and outlet pipe may be required to carry the drainage under the guardrail. If so, the drop inlet should have a grated opening and be flush with the ground.

(f) Depending on the steepness of the cut slope, a vehicle may ride up the slope some distance before redirection begins. Thus, it is possible for a vehicle which leaves the roadway in advance of the terminal to go around or over it.

If penetration is not acceptable, a longer run of barrier may be needed to create a recovery area between the terminal and the shielded hazard.

c. Proprietary Terminals - terminals in this category are generally patented and can only be licensed for manufacture or distribution through one source.

(1) As indicated in 23 CFR 635.411, products in this category are eligible for Federal funding provided:

(a) they are purchased through competitive bidding with equally suitable unpatented products;

(b) a State highway agency certifies that a specific product is essential for synchronization with existing highway facilities, or that no equally suitable alternate exists;

(c) a proprietary product is installed as an experimental feature for the purpose of in-service evaluation;

(d) such usage has been approved by FHWA's Division Administrator as being in the public interest.

(2) Currently, the principal proprietary terminals appropriate for use with w-beam/thrie-beam guardrails are the Safety End Treatment Terminal (SENTRE); the Crash-Cushion Attenuating Terminal (CAT); the BRAKEMASTER; and the ET-2000. A discussion of each follows:

(a) SENTRE

1 The SENTRE is manufactured by Energy Absorption Systems, Inc., of Chicago, Illinois, and is designed for installation on the end of a w-beam or thrie-beam guardrail. The SENTRE unit consists of interlocking, telescoping thrie-beam fender panels attached to steel wide flange, slip-base posts, plus sand containers and a ground-level redirecting cable. A tension cable is required to anchor the guardrail at the point of connection to the SENTRE. Detailed design, construction and maintenance information is available from the manufacturer.

2 The SENTRE can be installed parallel to the roadway or with a 1219-mm (4-foot offset). Although a relatively flat slope behind the terminal is preferred, a test with a 1.5:1 foreslope was successful. The redirecting cable prevents end-on impacting vehicles from striking the hard point at the beginning of the guardrail by guiding the vehicles along the cable behind the rail. The sand containers on the end posts dissipate some of the crash energy in the same manner as sand barrel crash cushions do. As with all slip-base devices, bolt torque is critical for proper impact performance and the manufacturer's specifications must be followed for construction and maintenance.

(b) CAT

1 The CAT is manufactured and distributed by Syro Steel Company, Girard, Ohio. It has evolved from the earlier Vehicle Attenuating Terminal (VAT) and the Combination Attenuating Terminal (also called CAT). The latest version of the CAT is the only one currently produced. It replaces both the VAT and the earlier CATs. It may be used both as a crash cushion and as a terminal for w-beam guardrail.

2 The CAT consists of slotted 3.43-mm (0.135-inch or 10-gage) thick base metal, and 2.67-mm (0.105-inch or 12-gage) thick base metal, w-beam rails that telescope in end-on impacts to dissipate crash energy. For side hits, the unit redirects vehicles in the same manner as standard w-beam guard rail. It is designed for parallel installation and, like all terminals, functions best when on terrain that allows a vehicle to strike it with little or no roll induced. Detailed design, construction and maintenance information is available from the manufacturer.

(c) BRAKEMASTER - the BRAKEMASTER is manufactured by Energy Absorption Systems, Inc., of Chicago, Illinois and is intended for use as a crash cushion and as a terminal for w-beam guardrail. This terminal consists primarily of an anchor assembly, a cable/brake assembly, and w-beam panels. It redirects vehicles during side impacts and telescopes in end-on hits, with the cable/brake assembly absorbing much of the crash energy. Detailed information on design, installation and maintenance is available from the manufacturer.

(d) ET-2000 - the ET-2000 is manufactured by Syro Steel Company of Girard, Ohio and is designed to fit on the end of a w-beam guardrail. The guardrail is anchored in a manner similar to the standard breakaway cable terminal (BCT), and redirects side-impacting vehicles. For an end-on hit, the ET-2000 essentially flattens and bends the w-beam shape, absorbing crash energy and directing the flattened w-beam away from an impacting vehicle. It is intended for use on the end of a w-beam installation with no flare. Detailed information can be obtained from the manufacturer. As with all terminals, where penetration behind and beyond the barrier can be expected, a traversable area is needed to aid post-crash vehicle stability and to prevent impact into fixed object hazards.

d. Departure-end Terminals - on multi-lane divided highways and one-way facilities, the downstream or departure end of a traffic barrier does not have to be crashworthy, but a structurally adequate anchorage is required to keep the rail in tension when it is struck near the trailing end. Some highway agencies add extra rail, often 15 m (approximately 50 feet), to the length needed to shield the hazard fully rather than install an anchor. This practice is not recommended because it adds unnecessary rail to the roadside which is not likely to perform properly if struck, increasing accident costs to motorists and installation and repair costs to the highway agencies. In addition, to create an effective anchor, rectangular washers should be used with the post bolts in this last 15 m (50 feet) of rail, a practice that has been discouraged for several years. In locations where a barrier end cannot be hit head-on, the best terminal to use is normally the simplest and least expensive. A turned-down terminal anchored in concrete or a cable-deadman anchorage system meet these two requirements. Where space permits, a downstream terminal should be installed with a slight flare to reduce the potential for snagging on the anchor system. However, flare rates sharper than approximately 8:1 should be avoided to minimize barrier deflection and to decrease the likelihood of pocketing a vehicle which strikes the rail near the departure end.

5. <u>RECOMMENDATIONS</u>

a. State highway agencies should be encouraged to review existing policies for selecting guardrail terminals, including proprietary devices, and to revise them as needed to ensure consistent use of the most cost effective terminal in each instance. States should also develop and implement a continuing accident review process to monitor field performance of existing barriers, terminals, and other roadside features.

b. FHWA field offices should continue to monitor State highway agencies' adherence to current policy regarding the use of turned-down terminals. Turned-down terminals used with weak-post w-beam systems must be designed insofar as practical to preclude high-speed vehicles from being launched into hazards behind the terminal or from being captured and guided on top of the rail to fixed-object hazards or steep slopes. Normally, this will require significantly longer or flared guardrail installations and/or flared terminals.

c. State highway agencies currently using the BCT should be aware of its limitations and encouraged to monitor their installations closely to determine if they are performing satisfactorily. If not, changes in the State's terminal selection, design, construction or maintenance procedures may be warranted. These agencies should also keep appraised of potential modifications to existing BCTs that could significantly improve their performance and to ensure that new BCT installations fully meet the recommendations contained in this Technical Advisory.

d. NCHRP Report 350, which is to be published in early 1993, will define three test levels for end treatments and crash cushions. All end treatments previously discussed are expected to fall into one of these three levels. If NCHRP 350 is subsequently adopted by the

FHWA, State highway agencies reviewing their policies may elect to incorporate the variable test level concept into their terminal selection procedures.

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