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A Study of Roadside Shoulder-Soil Index Properties, Drainage, And Regional Seismic Context in Ghaziabad-NCR

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Abstract
Roadside shoulder soils and surface-drainage conditions may be associated with visible pavement deterioration, although index tests alone cannot establish in-place subgrade strength or prove causation. This study compared natural moisture content, Atterberg limits, and free-swell index (FSI) across four roadside settings in the Ghaziabad–NCR region and considered these properties alongside a structured pavement-distress survey. Moisture contents ranged from 6.7% to 21.4%. Two samples showed plastic behaviour, with liquid limits of 48.6% and 29.4% and plasticity indices of 26.7% and 9.2%; the other two were non-plastic. FSI values calculated from whole-millilitre cylinder readings ranged from 0% to 44.4%. Fatigue-cracked areas ranged from 3.7% to 23.8% of a defined 60 m² wheel-path reference area, while mean shoulder drop-off ranged from 22.2 to 60.8 mm. The results show how soil-index properties and drainage context can be considered together, while recognizing that shoulder samples do not establish conditions beneath the paved wheel path and that the comparison cannot prove causation or determine site-specific liquefaction susceptibility. Regional seismic zonation is considered as background context only.

I. Introduction

Low-volume rural and peri-urban roads connect settlements with markets, schools, health facilities, and larger transport corridors. Water entering pavement cracks or remaining in roadside drains can contribute to deterioration, while unconfined shoulders can erode under runoff. Visible pavement condition is also influenced by construction quality, pavement structure, traffic loading, maintenance history, and materials. A small multi-site comparison can describe co-occurring conditions, but cannot isolate the effect of any one factor (Miller & Bellinger, 2014; Indian Roads Congress [IRC], 2015).

The Ghaziabad and adjacent Gautam Buddha Nagar area lies within the Upper Gangetic Plain. District agricultural contingency material provides broad regional context for soils and land use, but district-level descriptions cannot identify the composition of a specific roadside sample (ICAR-Central Research Institute for Dryland Agriculture [ICAR-CRIDA], 2012). Research on granular subbase permeability and low-volume road performance provides additional context for discussing drainage and surface distress (Kandlavath et al., 2020; Sahoo & Reddy, 2011).

Ghaziabad and Gautam Buddha Nagar are identified in district and state disaster-management materials as lying in seismic Zone IV under the IS 1893 (Part 1):2016 framework (Bureau of Indian Standards [BIS], 2016; Ghaziabad District Administration, n.d.; Uttar Pradesh State Disaster Management Authority [UPSDMA], 2022). Seismic zoning describes regional shaking hazard; it does not establish liquefaction susceptibility at a particular road. Site-specific assessment requires subsurface information about soil type and density, groundwater conditions, and seismic demand (Satyam & Rao, 2014).

The research question is: how can moisture content, Atterberg limits, free-swell index, and drainage context be compared with a structured summary of pavement distress across four representative roadside settings, and what are the limits of interpreting those observations within a regional Zone IV framework?

II. Methodology

2.1 Study area and site selection

Four roadside corridors were selected to represent a low-lying basin, a river-floodplain margin, an older alluvial plain, and a slightly elevated upland plain. The sites were compared using their broad regional setting, roadside drainage conditions, and pavement context. Sample collection was done mostly in the mornings to avoid peak-hour traffic.

Table 1. Roadside settings and local environmental context

Site/corridor label	Regional setting	Drainage context	Road context
1 — Badalpur–Dujana	Dadri / Greater Noida West area	Low-lying basin; slow-draining earthen ditches and ponding	Low-volume bituminous road; agricultural and local traffic
2 — Karhera–Morta	Hindon floodplain area, Ghaziabad	Floodplain margin; sandy shoulder exposed to runoff and edge erosion	Low-volume bituminous road; local and farm utility traffic
3 — Dasna–Masuri	Older alluvial / irrigated plain, Ghaziabad district	Partly obstructed cross-drainage culvert	Low-volume bituminous road; agricultural and local passenger traffic
4 — Niwari–Patla	Northern upland plain near Modinagar	Slightly elevated setting with open roadside drainage	Low-volume bituminous road; village and agricultural traffic

2.2. Soil sampling and index testing

One disturbed soil sample was taken from the unpaved shoulder at each corridor, approximately 0.3 m beyond the asphalt edge at a depth of 0.35–0.45 m after removal of about 0.15 m of loose surface material. The samples represented adjacent shoulder or embankment material rather than soil directly beneath the paved wheel path. A bulk sample of about 1 kg per site was collected.

Natural moisture content was calculated from net wet and net oven-dry soil mass using w_n (%) = [(M_1 − M_2) / M_2] × 100. For this determination, the sealed moisture sub-samples were dried in a thermostatically controlled oven at 105–110°C for approximately 24 hours, cooled, and reweighed in accordance with IS 2720 (Part 2):1973 (Bureau of Indian Standards [BIS], 1973). Table 2 reports tare and gross masses so the net sample masses and calculated moisture contents can be checked.

For the Atterberg tests, air-dried soil passing the 425 μm sieve was tested in accordance with IS 2720 (Part 5):1985 (BIS, 1985). Liquid limit was estimated with a hand-operated Casagrande cup from four water-content trials by plotting moisture content against $\log_{10}$ blow count and evaluating the fitted line at 25 blows. Plastic limit was taken as the mean of two thread-rolling determinations at the conventional 3 mm endpoint. Plasticity index was calculated as PI = LL − PL, and liquidity index as LI = (w_n − PL) / PI for samples with a plastic response. Samples that could not be rolled into a reproducible 3 mm thread were recorded as non-plastic (NP).

The FSI test followed the water-versus-kerosene comparison described in IS 2720 (Part 40):1977 (BIS, 1977). Separate 10 g oven-dried portions passing the 425 μm sieve were placed in 100 mL graduated cylinders, left to settle for at least 24 hours, and read at the available whole-millilitre graduations. FSI was calculated as [(Vw − Vk) / Vk] × 100. Because a complete particle-size distribution was not available, no formal IS 1498 soil-group symbol was assigned.

Laboratory testing was carried out with assistance from a civil-engineering graduate using available college laboratory equipment and, where applicable, home/school testing equipment. The selected soil-index tests followed the applicable testing procedures and standards described above, and the resulting measurements were used for subsequent analysis.

Not all equipment used was laboratory-grade, and differences in equipment resolution, setup, and operator technique may have introduced measurement variability. The results should therefore be interpreted with these potential sources of error in mind.

2.3. Pavement-distress metrics and seismic context

A 50 m road segment was surveyed at each corridor. Fatigue-cracked area was estimated by summing the approximate length-times-average-width areas of visible interconnected patches within two 0.6 m-wide wheel-path strips, giving a reference area of 2 × 0.6 m × 50 m = 60.0 m²; the estimated patch area was divided by 60.0 m². Longitudinal and edge-crack lengths were expressed per 50 m segment. Mean rut depth was calculated from ten readings across five longitudinal stations and two wheel paths. Mean shoulder drop-off was calculated from five stations at 10 m intervals. The terminology follows the Federal Highway Administration distress-identification manual (Miller & Bellinger, 2014). The regional Zone IV designation was included as context; groundwater measurements, borehole logs, SPT values, density profiles, and shear-wave-velocity data were not available.

III. Results

3.1. Natural moisture content

Moisture contents ranged from 6.7% to 21.4%. Site 1 had the highest calculated moisture content, while Site 4 had the lowest. The values were calculated from the net sample masses reported in Table 2.

Table 2. Tare, gross mass, and calculated natural moisture content

Site	Tin tare (g)	Tin + wet soil (g)	Tin + dry soil (g)	Net wet/dry soil (g)	w_n (%)
1 — Badalpur–Dujana	22.47	97.08	83.94	74.61 / 61.47	21.4
2 — Karhera–Morta	21.82	91.64	82.70	69.82 / 60.88	14.7
3 — Dasna–Masuri	23.15	88.38	81.49	65.23 / 58.34	11.8
4 — Niwari–Patla	22.63	86.44	82.45	63.81 / 59.82	6.7

3.2. Atterberg limits and free-swell index

The two plastic soils differed in their index properties. Site 1 had LL = 48.6%, PL = 21.9%, and PI = 26.7%; Site 3 had LL = 29.4%, PL = 20.2%, and PI = 9.2%. In each case, the rounded values of LL and PL reproduce the reported PI. Sites 2 and 4 were non-plastic (NP), so LL, PL, PI, and LI values were not assigned. No formal soil-group symbol was assigned because a complete grain-size distribution was not available.

Table 3. Liquid-limit trials and calculated Atterberg indices

Site	Liquid-limit trials (blows: water content, %)	LL (%)	PL (%) (two results; mean)	PI (%)	LI
1 — Badalpur–Dujana	34: 46.6; 28: 48.0; 21: 49.7; 16: 51.4	48.6	21.2, 22.5; mean 21.9	26.7	−0.02
2 — Karhera–Morta	Non-plastic response; no LL assigned	NP	NP	NP	—
3 — Dasna–Masuri	31: 28.2; 26: 29.2; 22: 30.1; 17: 31.4	29.4	19.8, 20.6; mean 20.2	9.2	−0.91
4 — Niwari–Patla	Non-plastic response; no LL assigned	NP	NP	NP	—

FSI values were calculated from cylinder readings rounded to whole millilitres, consistent with the resolution of the stated apparatus. Site 1 showed the largest water-versus-kerosene difference. FSI is a comparative index and does not by itself establish field swelling pressure or determine a treatment requirement (BIS, 1977).

Table 4. Free-swell-index calculation using whole-millilitre readings

Site	Settled volume in water, Vw (mL)	Settled volume in kerosene, Vk (mL)	FSI (%)
1 — Badalpur–Dujana	13	9	44.4
2 — Karhera–Morta	9	9	0.0
3 — Dasna–Masuri	11	10	10.0
4 — Niwari–Patla	10	9	11.1

3.3. Pavement-distress comparison

The distress survey showed the highest fatigue-cracking percentage and mean rut depth at Site 1 and the largest shoulder drop-off at Site 2. Site 4 had the lowest cracking estimate and mean rut depth. These patterns were considered alongside soil-index properties and drainage setting, while recognizing that pavement condition is affected by factors beyond the tested shoulder material.

Table 5. Pavement-distress survey summary for a 50 m segment at each site

Metric	Site 1: Badalpur–Dujana	Site 2: Karhera–Morta	Site 3: Dasna–Masuri	Site 4: Niwari–Patla
Fatigue-cracked wheel-path area	14.3 m² (23.8%)	4.7 m² (7.8%)	6.7 m² (11.2%)	2.2 m² (3.7%)
Longitudinal and edge cracks (m / 50 m)	20.6	14.4	6.2	7.4
Mean rut depth (mm; n = 10)	19.8 (11–31)	14.4 (8–21)	11.7 (6–17)	6.9 (3–11)
Potholes (per 50 m)	4	1	2	0
Mean shoulder drop-off (mm; n = 5)	34.6 (19–52)	60.8 (38–79)	22.2 (12–34)	27.4 (15–39)
Drainage setting	Ponded / obstructed ditches	Scoured sandy shoulder	Partly obstructed culvert	Open, dry ditches
Regional seismic context	Zone IV	Zone IV	Zone IV	Zone IV

IV. Discussion

4.1. Interpreting index values alongside drainage

Site 1 combined the highest moisture content with PI = 26.7% and a moisture content close to its plastic limit. Its drainage setting included ponding, and its distress summary showed the highest cracking percentage and mean rut depth. These co-occurring indicators are consistent with a possible drainage-related mechanism, but the comparison cannot demonstrate causation or confirm that shoulder soil represents the material beneath the carriageway. The FSI value of 44.4% should be treated as an index comparison rather than conclusive evidence of substantial expansion; mineralogy, seasonal behaviour, and suitable strength or volume-change tests would be needed for a fuller assessment.

Site 3 had a lower PI and a moisture content well below its PL. Sites 2 and 4 were non-plastic, while Site 2 had the largest shoulder drop-off. This pattern is compatible with the possibility that runoff and shoulder confinement influence edge condition, but these effects cannot be separated from pavement age, layer thickness, construction quality, traffic, or maintenance. Formal soil classification would require complete grain-size information.

4.2. Regional seismic context

The regional Zone IV designation is shared by all four sites and does not explain variation in the pavement-distress metrics. The sites are considered within the seismic-zoning framework of IS 1893 (Part 1):2016 (BIS, 2016; Ghaziabad District Administration, n.d.; UPSDMA, 2022). Groundwater depths and subsurface density values were not measured as part of this investigation. The floodplain setting at Site 2 may warrant careful investigation in an engineering project, but liquefaction susceptibility cannot be concluded from surface index properties alone. A site-specific assessment would require groundwater and subsurface testing, such as Standard Penetration Test data and/or shear-wave-velocity profiling (Satyam & Rao, 2014).

4.3. Maintenance implications

Where comparable conditions are confirmed by a site investigation, routine actions could include clearing obstructed drains, restoring shoulder support where edge loss is present, and inspecting culverts before the monsoon. Where plastic soils are suspected of contributing to distress, engineers would need appropriate mix-design and strength testing before considering lime or other stabilizers. The index values alone are insufficient to select stabilizer dosage, design a pavement, or prescribe site-specific treatment (IRC, 2010, 2015, 2018).

V. Limitations and Future Research

Several limitations should be considered when interpreting the comparison. One shoulder sample and one short distress segment were considered per site; shoulder samples remain proxies rather than direct measurements of soil beneath wheel paths. The programme did not include a complete particle-size distribution, compaction curve, soaked California Bearing Ratio (CBR), in-place density, groundwater monitoring, borehole SPT, or shear-wave-velocity profile. Construction age, pavement-layer thickness, cumulative axle loading, and maintenance history were not controlled. Further work should collect replicate samples, record locations and dates, retain raw laboratory and field sheets, and monitor drainage and pavement distress across wet and dry seasons.

The use of equipment with varying levels of precision and differences in setup or operator technique may have introduced measurement uncertainty. Future testing should use appropriately calibrated laboratory equipment and replicate measurements to improve the reliability of the results.

VI. Conclusion

Across the four sites, Site 1 had the highest moisture content, plasticity index, cracking percentage, and mean rut depth, while Site 2 had the largest shoulder drop-off. These contrasts suggest hypotheses for further geotechnical investigation but do not prove that soil properties or drainage alone caused the observed distress. Regional seismic Zone IV information provides context only; without site-specific groundwater and subsurface data, liquefaction susceptibility cannot be determined.

Appendix A. Individual pavement readings used in the summary statistics

The individual readings below reproduce the arithmetic means and ranges reported in Table 5.

Table A1. Rut-depth readings (mm) at five stations across two wheel paths

Site	Individual readings (mm)	Mean (mm)	Range (mm)
1 — Badalpur–Dujana	11, 16, 19, 22, 31, 18, 14, 26, 17, 24	19.8	11–31
2 — Karhera–Morta	8, 12, 16, 21, 13, 14, 17, 10, 18, 15	14.4	8–21
3 — Dasna–Masuri	6, 9, 13, 17, 11, 10, 15, 8, 12, 16	11.7	6–17

Site	Individual readings (mm)	Mean (mm)	Range (mm)
4 — Niwari–Patla	3, 5, 8, 11, 6, 7, 10, 4, 9, 6	6.9	3–11

Table A2. Shoulder drop-off readings (mm) at five stations

Site	Individual readings (mm)	Mean (mm)	Range (mm)
1 — Badalpur–Dujana	19, 27, 34, 41, 52	34.6	19–52
2 — Karhera–Morta	38, 55, 68, 79, 64	60.8	38–79
3 — Dasna–Masuri	12, 21, 25, 34, 19	22.2	12–34
4 — Niwari–Patla	15, 26, 39, 33, 24	27.4	15–39

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