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ENHANCING THE ENGINEERING PROPERTIES OF BLACK COTTON SOIL USING SEA SALT

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ABSTRACT

Black cotton soil is one of the most common soil types in India, covering over 20% of the country's land area. Also known as "regur," it is rich in montmorillonite clay minerals, which cause significant swelling and shrinkage behavior. These properties pose serious challenges to the stability of structures built on such soil, especially lightweight constructions. In this study, laboratory experiments were conducted to assess the impact of sea salt as a stabilizing agent for black cotton soil. The results showed a notable reduction in plasticity and improved load-bearing characteristics. The liquid limit decreased from 65.80% to 48.15%, plastic limit from 42.20% to 34.77%, and the plasticity index from 23.60% to 13.38% at 8% sea salt content. Specific gravity dropped from 2.556 to 2.339, and optimum moisture content increased from 16.8% to 20.4%, while maximum dry density reduced from 1.68 g/cc to 1.50 g/cc. The California Bearing Ratio (CBR) at 2.5 mm penetration improved from 3.5% to 5.6% with 10% sea salt. These results suggest that the inclusion of 6–8% sea salt significantly enhances the engineering properties of black cotton soil at minimal cost, making it a viable and economical solution for soil stabilization in geotechnical and highway applications.

1. INTRODUCTION:

The rising costs associated with the use of high-quality construction materials have led to the increased utilization of locally available soils in geotechnical and highway engineering projects. However, these local soils often present challenges such as high-water content and low workability, which can hinder construction activities. In many cases, the soil found on-site is problematic, especially expansive soils, which are known for their high swelling and shrinkage behaviour. Expansive soils tend to heave during periods of high moisture, causing the uplift of buildings and other structures. Conversely, during dry conditions, they shrink, potentially leading to settlement issues. These soils can also exert lateral pressure on the vertical faces of foundations, basements, and retaining walls, resulting in unwanted movements. Beyond their impact on buildings and foundations, expansive soils significantly affect roads, ground anchors, underground pipelines, and other buried infrastructure. Pavements are particularly vulnerable to damage from expansive soils due to their lightweight nature and broad surface coverage. In India, expansive soils cover nearly 20% of the land area, making it impractical to avoid them in construction and pavement projects. Therefore, addressing the challenges posed by expansive soils is crucial, and various soil improvement methods are available to enhance their engineering properties.

Previous research on enhancing the properties of expansive soils has yielded effective solutions, particularly through chemical stabilization techniques and deep foundation methods. Among these, stabilization techniques

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have proven to be the most impactful. In a broad sense, stabilization encompasses various methods used to modify soil properties with the goal of reducing construction costs by utilizing locally available materials.

Simultaneously, large quantities of salt are produced from the sea every day, making its utilization an important consideration. Salt is generally classified into two types: sea salt and table salt (common salt). Sea salt is obtained by evaporating ocean water or water from saltwater lakes, usually with minimal processing. Depending on the source, sea salt retains certain trace minerals and elements, which contribute to its distinctive flavour, colour, and varying levels of coarseness. In contrast, table salt is typically mined from underground salt deposits. It undergoes extensive processing to remove minerals and often includes additives to prevent clumping. Despite these differences, sea salt and table salt contain similar amounts of sodium by weight.

1.1. NEED OF THIS RESEARCH:

Several studies have been conducted in the past to investigate the problems and structural damages caused by black cotton soil. A considerable amount of research has focused on improving the engineering properties of expansive soils using economical and effective methods, including the use of common salt. However, comparatively less attention has been given to the use of sea salt, which is abundantly available at minimal or no cost. Therefore, there is a need to explore the effects of sea salt on the engineering properties of expansive soils such as black cotton soil.

1.2. OBJECTIVES OF RESEARCH:

- To analyse and evaluate the fundamental properties of black cotton soil.
- To investigate the impact of sea salt on the index properties of black cotton soil.
- To examine the influence of sea salt mixtures on the engineering properties of black cotton soil.
- To determine the most effective sea salt mixture for optimal soil stabilization.

2. LITREATURE REVIEW:

Cokca and Yilmaz (2004) examined the strength and hydraulic behaviour of a bentonite-amended fly ash mixture used as a liner material, incorporating rubber content up to 10%. Their results indicated that increasing rubber content led to higher hydraulic conductivity and compressibility, along with reduced unconfined compressive strength (UCS).

Narani et al. (2020) investigated the effect of tire textile fibres (at 1%, 2%, 3%, and 4%) on sodium bentonite for liner applications. They found that at 4% fibre content, the swell potential and volumetric shrinkage were reduced by 36.7% and 12.3%, respectively, compared to pure bentonite.

Mukherjee and Mishra (2021) studied the incorporation of tire fibres (5%, 10%, and 15%) into a sand-bentonite mixture and reported significant improvements in shear strength parameters and reduced shrinkage strains. For the unreinforced sand-bentonite mix, the cohesion and angle of internal friction were 15 kPa and 21°, respectively. These values increased to 24.2 kPa and 24.2° after 15% fibre reinforcement.

Mishra et al., 2005; Li et al., 2007 Another critical factor affecting the performance of liner materials is their interaction with chemicals, particularly salts present in municipal solid waste (MSW) leachates. Several studies have shown that incineration of MSW significantly reduces its volume, but the resulting bottom ash and fly ash deposited in landfills contain high concentrations of calcium (Ca^{2+}) and sodium (Na^{+}) ions.

The presence of these cations at high concentrations has been found to reduce the thickness of the diffuse double layer (DDL), thereby adversely affecting the performance of liner materials **(Shackelford et al., 2000; Shariatmadari et al., 2011; Dutta and Mishra, 2016; Jadda and Bag, 2020; He et al., 2021).** As a result, many researchers have investigated the impact of salt solutions on the engineering behavior of liners. For instance, **Shirazi et al. (2011) and Dutta and Mishra (2015)** observed that bentonites exposed to salt environments exhibited reduced liquid limits and swelling capacities as salt concentration increased.

Xue et al. (2012) studied the effect of both monovalent (KCl, NaCl) and divalent ($MgCl_2$, $CaCl_2$) salt solutions on geosynthetic clay liner (GCL) materials and found that $CaCl_2$ resulted in the highest hydraulic conductivity, followed by $MgCl_2$, KCl, and NaCl. Consolidation behaviour is another key parameter in assessing liner material performance. Robinson and Allam (1998) highlighted the influence of clay mineralogy and pore fluids on the coefficient of consolidation (cv). Dutta and Mishra (2016) reported that the cv of high-quality bentonite increased from 1.03×10^{-5} cm²/s to 5.25×10^{-5} cm²/s when subjected to 0–1N $CaCl_2$ under a pressure of 784.5 kPa. Correspondingly, the time required to achieve 90% consolidation (t90) decreased from 918.1 minutes to 132.2 minutes under the same conditions.

Jadda and Bag (2020) evaluated two types of bentonites—monovalent and divalent—under salt exposure. They observed that the hydraulic conductivity of monovalent bentonite increased by approximately 76 times and 41 times in 1N NaCl and $CaCl_2$ solutions, respectively, compared to distilled water. In contrast, divalent bentonites exhibited less dramatic increases. Rout and Singh (2020) examined the effect of monovalent, divalent, and trivalent inorganic salt permeants (0.1–1N concentrations) on the mechanical and hydraulic properties of bentonite mixed with pond ash and sand. Their results indicated that hydraulic conductivity increased by about twofold and tenfold for monovalent and trivalent salts, respectively, at 0.6M concentration. However, unconfined compressive strength (UCS) values were lower for trivalent salts compared to monovalent ones.

Several researchers have also studied the compression characteristics of soil–bentonite composites, reporting reduced compressibility in the presence of high-concentration salt solutions used as pore fluids **(Mishra et al., 2005; Shariatmadari et al., 2011; He et al., 2021).**

3. MATERIAL & METHODOLOGY:

3.1. BLACK COTTON SOIL:

Natural black cotton soil was collected from a site located behind Govt. Polytechnic College, Sironj near Lateri Road, in the Vidisha district of Madhya Pradesh. The soil sample was excavated from a depth of 1 meter below the natural ground level. It appeared dark grey to black in color. After collection, the soil was air-dried, manually pulverized, and sieved through both 425-micron and 4.75 mm IS sieves for testing. This type of soil is known for its high-volume change behavior and the formation of cracks during dry seasons, particularly in summer. The predominant clay mineral present in this soil is montmorillonite, which is primarily responsible for its expansive nature.

3.2. SEA SALT:

Sea salt, also known as common salt, table salt, or halite, is a chemical compound with the formula NaCl. Sodium chloride is primarily responsible for the salinity of seawater and the extracellular fluid of many multicellular organisms. As the main ingredient in edible salt, it is widely used as both a condiment and a food preservative. Sea salt is typically produced through the evaporation of seawater or brine from other sources, such as brine wells and salt lakes, and by mining rock salt, also known as halite. In 2002, the global production of sea salt was estimated at 210 million metric tonnes, with the top five producers being the United States (40.3 million tonnes), China (32.9 million tonnes), Germany (17.7 million tonnes), India (14.5 million tonnes), and Canada (12.3 million tonnes). India has an abundant supply of sea salt. However, there has been relatively little research on its use, despite its availability in large quantities and at minimal or no cost. Therefore, there is a pressing need to study the impact of sea salt on the engineering properties of expansive soils such as black cotton soil.

Table 1 Mix Proportion

Black Cotton Soil Percentage (%)	**Sea Salt Percentage (%)**	**Weight of Sea Salt (grams)**	**Weight of Black Cotton Soil (grams)**
100%	0%	0	5000
98%	2%	100	4900
96%	4%	200	4800
94%	6%	300	4700
92%	8%	400	4600
90%	10%	500	4500

3.3. METHODOLOGY:

The experimental investigation was carried out to study the effects of sea salt on the engineering properties of black cotton soil. The soil sample used in the study was collected from a site located behind the Government Polytechnic College, Sironj, near Lateri Road in the Vidisha district of Madhya Pradesh. The soil was excavated from a depth of approximately one meter below the natural ground surface. After collection, the soil was air-dried, manually pulverized, and then sieved through 425-micron and 4.75 mm Indian Standard sieves to ensure uniformity in particle size. The collected soil exhibited a dark grey to black color, typical of black cotton soil, and was rich in montmorillonite clay minerals known for their high swelling and shrinkage characteristics.

For stabilization, sea salt was selected due to its abundant availability and minimal processing cost. The sea salt, primarily composed of sodium chloride (NaCl), was obtained in its raw form through natural evaporation processes. To prepare test samples, black cotton soil was mixed with varying proportions of sea salt by weight. Six different mixes were prepared with sea salt contents of 0% (control), 2%, 4%, 6%, 8%, and 10%, maintaining a total sample weight of 5000 grams for consistency. The respective weights of soil and salt were adjusted accordingly for each mix.

A series of laboratory tests were conducted on both untreated and treated soil samples to evaluate the influence of sea salt on their engineering behaviour. Specific gravity tests were performed to assess the relative density changes in the soil due to salt addition. The Atterberg limits test, including the liquid limit, plastic limit, and plasticity index, was conducted to determine the consistency and plastic behaviour of the soil. The Proctor compaction test was carried out to evaluate the optimum moisture content (OMC) and maximum dry density (MDD) for each mix, indicating the compaction characteristics. Finally, the California Bearing Ratio (CBR) test was conducted at penetration depths of 2.5 mm and 5.0 mm to measure the improvement in subgrade strength due to sea salt treatment. The results from these tests provided comprehensive insights into the effectiveness of sea salt in enhancing the geotechnical properties of black cotton soil.

4. RESULT AND DISCUSSION

4.1. RESULT:

4.1.1. SPECIFIC GRAVITY:

The table illustrates the effect of increasing sea salt content on the specific gravity of Black Cotton Soil (B.C.S.). As the proportion of sea salt increases from 2% to 10%, the percentage of Black Cotton Soil correspondingly decreases from 98% to 90%. This progressive replacement leads to a consistent decline in specific gravity values—from 2.556 at 2% sea salt to 2.339 at 10% sea salt. The trend indicates that the addition of sea salt reduces the density of the soil particles, which may be attributed to the lighter or more porous nature of the salt particles compared to the original soil matrix. This information is crucial for understanding how salt contamination or intentional stabilization with salt could affect the soil's engineering properties.

Table 2: Variation of Specific Gravity with Sea Salt Content in Black Cotton Soil

Type of Soil	Specific Gravity Value (%)
98% B.C.S. + 2% Sea Salt	2.556
96% B.C.S. + 4% Sea Salt	2.515
94% B.C.S. + 6% Sea Salt	2.483
92% B.C.S. + 8% Sea Salt	2.427
90% B.C.S. + 10% Sea Salt	2.339

4.1.2. ATTERBERG LIMIT

Atterberg limit shows the state of transition of the soil sample from liquid to semi-solid and solid state. The liquid, plastic and plasticity index are an index of the number of fines present within a soil samples. Results obtained from a mixture of Black cotton soil with Sea salt. Table no. represents the Atterberg limit with of Black cotton Soil

Table 3 Atterberg Limit

Sea Salt Content (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
0 (100% B.C.S.)	65.80	42.20	23.60
98% B.C.S. + 2% Sea Salt	60.47	40.18	20.29
96% B.C.S. + 4% Sea Salt	56.46	38.72	17.74
94% B.C.S. + 6% Sea Salt	53.01	37.05	15.96
92% B.C.S. + 8% Sea Salt	48.15	34.77	13.38
90% B.C.S. + 10% Sea Salt	50.00	31.54	18.46

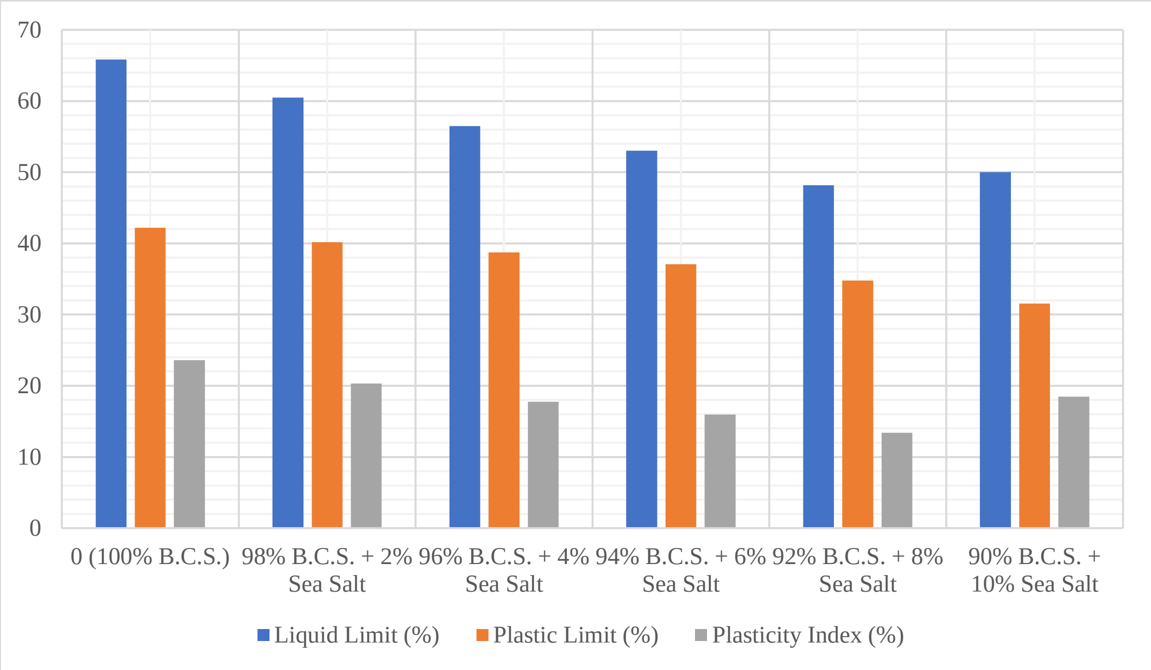

Figure 1 Graph of Atterberg Limit

Figure 1 represent the addition of sea salt to Black Cotton Soil (B.C.S.) significantly alters its Atterberg Limits. The Liquid Limit (LL) and Plastic Limit (PL) both decrease steadily up to 8% salt content, showing reduced water-holding capacity and plasticity. The Plasticity Index (PI), which indicates soil expansiveness, drops from 23.60% (at 0%) to 13.38% (at 8%), suggesting improved workability and lower swelling potential. However, a slight rise in LL and PI at 10% may suggest the start of salt-induced flocculation or imbalance, indicating 6–8% salt as an optimal treatment range for stabilization.

4.1.3. PROCTOR COMPACTION TEST:

The relationship between the maximum dry unit weight and optimum moisture content of Black cotton Soil and Sea salt at the different percentage. Here is the tabular form of Compaction test are followed

Table 4 Proctor Compaction Test

98% B.C.S. + 2% Sea Salt – OMC and MDD		
Trial No.	Optimum Moisture Content (OMC %)	Maximum Dry Density (MDD g/cc)
1	16.8	1.66
2	17.0	1.67
3	17.2	1.68
4	17.4	1.66
5	17.7	1.67
96% B.C.S. + 4% Sea Salt – OMC and MDD		
1	17.5	1.64
2	17.7	1.65
3	17.9	1.66
4	18.1	1.64

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5	18.4	1.62
94% B.C.S. + 6% Sea Salt – OMC and MDD		
1	18.1	1.62
2	18.4	1.63
3	18.6	1.61
4	18.3	1.62
5	19.1	1.57
92% B.C.S. + 8% Sea Salt – OMC and MDD		
1	18.7	1.60
2	19.0	1.59
3	19.2	1.58
4	19.3	1.57
5	19.6	1.55
90% B.C.S. + 10% Sea Salt – OMC and MDD		
1	19.3	1.56
2	19.5	1.57
3	19.8	1.58
4	20.1	1.53
5	20.4	1.5

Table 4 represent the results from the Proctor compaction tests indicate a clear trend in the behaviour of Black Cotton Soil (B.C.S.) stabilized with varying percentages of sea salt. As the sea salt content increases from 2% to 10%, the Optimum Moisture Content (OMC) steadily rises. For instance, at 2% salt, the OMC ranges around 16.8%–17.7%, while at 10% salt, it increases to about 19.3%–20.4%. This rise in moisture requirement can be attributed to the hygroscopic nature of sea salt, which draws more water into the soil mass to achieve optimum compaction.

In contrast, the Maximum Dry Density (MDD) exhibits a decreasing trend with higher salt content. For example, the MDD is approximately 1.66–1.68 g/cc at 2% salt, but it drops to 1.50–1.58 g/cc at 10% salt. This reduction is due to flocculation and particle rearrangement effects caused by the salt, leading to a less dense packing of soil particles. Overall, the addition of sea salt to B.C.S. improves the soil's moisture-holding capacity but reduces its compacted density. This information is vital for field compaction control in geotechnical and pavement applications, suggesting an optimal salt range (possibly around 4–6%) where a balance between moisture and density might be achieved for better soil stability.

4.1.4. CALIFORNIA BEARING RATIO:

In the given table represent the CBR value of Black Cotton Soil with the different percentages of Sea Salt. Table represent the CBR value of black Cotton Soil with Sea Salt

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Table 5 California Bearing Ratio of Black Cotton Soil

Type of Soil	CBR @ 2.5 mm (%)	CBR @ 5.0 mm (%)
100% B.C.S.	**3.5**	**3.2**
98% B.C.S. + 2% Sea Salt	4.2	3.8
96% B.C.S. + 4% Sea Salt	4.6	4.1
94% B.C.S. + 6% Sea Salt	5.0	4.5
92% B.C.S. + 8% Sea Salt	5.3	4.8
90% B.C.S. + 10% Sea Salt	5.6	5.0

From figure 4 the California Bearing Ratio (CBR) test results for Black Cotton Soil (B.C.S.) treated with increasing percentages of sea salt indicate a consistent improvement in subgrade strength. As the sea salt content increases from 2% to 10%, the CBR value at 2.5 mm penetration improves from 4.2% to 5.6%, and the CBR at 5.0 mm increases from 3.8% to 5.0%. This enhancement may be attributed to the salt's binding effect, which reduces plasticity and enhances load-bearing capacity. Typically, the 2.5 mm CBR value is higher than 5.0 mm, and since CBR design uses the higher of the two, the 2.5 mm value is usually adopted for pavement layer design. These results show that adding sea salt to B.C.S. can improve its suitability for road construction applications**.**

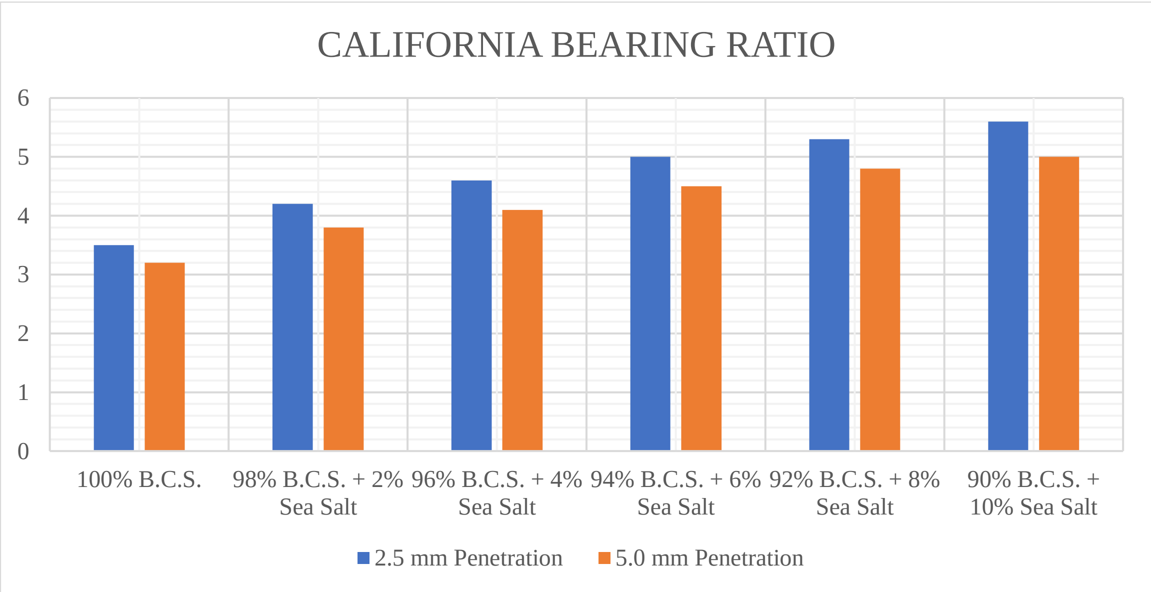

Figure 4 California Bearing Ratio

The California Bearing Ratio (CBR) test results for Black Cotton Soil (B.C.S.) treated with increasing percentages of sea salt indicate a consistent improvement in subgrade strength. As the sea salt content increases from 2% to 10%, the CBR value at 2.5 mm penetration improves from 4.2% to 5.6%, and the CBR at 5.0 mm increases from 3.8% to 5.0%. This enhancement may be attributed to the salt's binding effect, which reduces plasticity and enhances load-bearing capacity. Typically, the 2.5 mm CBR value is higher than 5.0 mm, and since CBR design uses the higher of the two, the 2.5 mm value is usually adopted for pavement layer design. These results show that adding sea salt to B.C.S. can improve its suitability for road construction applications**.**

5. CONCLUSION:

The present study demonstrates that sea salt can be effectively used as a low-cost stabilizing agent to improve the engineering properties of black cotton soil. The addition of sea salt led to a consistent reduction in the specific gravity, liquid limit, plastic limit, and plasticity index of the soil, indicating a decrease in its expansiveness and improved workability. The Proctor compaction test results showed that while the optimum moisture content increased with higher salt content due to the hygroscopic nature of salt, the maximum dry density decreased slightly because of the flocculation and rearrangement of soil particles. Furthermore, the California Bearing Ratio (CBR) values showed a marked improvement with the inclusion of sea salt, indicating enhanced load-bearing capacity and suitability for subgrade applications in pavement construction. Based on the findings, an optimal sea salt content between 6% and 8% appears most effective for stabilizing black cotton soil, balancing improvements in strength with manageable moisture and compaction characteristics. This study supports the use of sea salt as an economical and efficient stabilizer for expansive soils, particularly in regions where conventional stabilization methods are cost-prohibitive.

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